INDUSTRIAL ADOPTION OF MODEL-BASED SYSTEMS ENGINEERING: AN INVESTIGATION WITHIN THE DEFENCE INDUSTRY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF INFORMATICS OF
THE MIDDLE EAST TECHNICAL UNIVERSITY
BY

ALİTAN BAYRAMOĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
THE DEPARTMENT OF INFORMATION SYSTEMS

JANUARY 2022

INDUSTRIAL ADOPTION OF MODEL-BASED SYSTEMS ENGINEERING: AN INVESTIGATION WITHIN THE DEFENCE INDUSTRY

Submitted by ALİTAN BAYRAMOĞLU in partial fulfillment of the requirements for the degree of **Master of Science in Information Systems Department, Middle East Technical University** by,

Prof. Dr. Deniz Zeyrek Bozşahin
Dean, **Graduate School of Informatics** ____________________

Prof. Dr. Sevgi Özkan Yıldırım
Head of Department, **Information Systems** ____________________

Prof. Dr. Sevgi Özkan Yıldırım
Supervisor, **Information Systems, METU** ____________________

Examining Committee Members:

Assoc. Prof. Dr. Farid Huseynov
Management Dept., Gebze Technical University ____________________

Asst. Prof. Dr. Özden Özcan Top
Information Systems Dept., METU ____________________

Prof. Dr. Sevgi Özkan Yıldırım
Information Systems Dept., METU ____________________

Date: 24.01.2022

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Alitan BAYRAMOĞLU

Signature : ____________________

ABSTRACT

INDUSTRIAL ADOPTION OF MODEL-BASED SYSTEMS ENGINEERING: AN INVESTIGATION WITHIN THE DEFENCE INDUSTRY

Bayramoğlu, Alitan
MSc., Department of Information Systems
Supervisor: Prof. Dr. Sevgi Özkan Yıldırım

January 2022, 134 pages

Increasing competition in contemporary industrial settings drive organizations to unceasingly seek ways to improve the overall quality of their products and services, and the processes followed in order to procure them. Model-Based Systems Engineering (MBSE) has been put forth with promises to remedy shortcomings constituted by legacy document-based engineering approaches. However, for an organization to fully adopt MBSE, it must overcome several human, financial, organizational and technological factors. The purpose of this study was to elucidate these factors that are in affect for potential MBSE adopters clearly. In order to achieve this, research within the literature has led to the identification of a theoretical model that comprises of the most significant latent constructs that are in effect in MBSE adoption. The resulting technology adoption model's explanatory power was evaluated in a quantititative manner via a questionnaire, with participants chosen from engineering practitioners in Turkey, who are experienced in the matter. The proposed structural model was validated and refined using Partial Least Squares Structural Equation Modelling (PLS-SEM). The resulting adoption model was developed that aims to explain the relations between factors that are in effect in MBSE adoption.

Keywords: Model-Based Systems Engineering, Systems Engineering, Adoption, Defence Industry, Technology Adoption Model

ÖZ

MODEL TABANLI SİSTEM MÜHENDİSLİĞİ'NİN ENDÜSTRİDE BENİMSENMESİ: SAVUNMA SANAYİ'NDE BİR ARAŞTIRMA

Bayramoğlu, Alitan
Yüksek Lisans, Bilişim Sistemleri Bölümü
Tez Yöneticisi: Prof. Dr. Sevgi Özkan Yıldırım

Ocak 2022, 134 sayfa

Modern endüstriyel çevrelerde giderek artan rekabet içerisinde bulunan organizasyonlar, sundukları ürün ve hizmetlerin kalitesini, ve buna bağlı olarak ürün ve hizmetleri ortaya çıkarmakta kullandıkları süreçleri sürekli olarak artırma çabası içerisinde bulunmalarını gerektirmektedir. Model tabanlı sistem mühendisliği (MTSM), günümüzde ağırlıklı olarak izlenilen doküman tabanlı yaklaşımlardan miras kalan yetersizlikleri giderebileceği sözüyle birlikte sunulmakta. Ancak, herhangi bir şirketin model tabanlı yaklaşımları benimseyebilmesi için, bu yolda ortaya çıkan bir takım beşeri, iktisadi, organizasyonel ve teknolojik hususların üstesinden gelebilmeleri gerekmektedir. Model tabanlı yaklaşımları benimseme ihtimali olan organizasyonlar için karşılarına çıkabilecek hususların açık bir şekilde ortaya çıkarılması amacıyla yapılan bu çalışmada, konuyla ilgili literatür taraması dahilinde elde edilen faktörler ve ilişkiler, teorik bir model kapsamında bir araya getirilmiştir. Ortaya çıkan teknoloji benimseme modelinin açıklama gücü, Türkiye'de konuya vakıf mühendislik pratisyenlerinin katıldığı bir anket yardımıyla nicel olarak değerlendirilmiştir. Yapısal modelin işleyişi Kısmi En Küçük Kareler ile Yapısal Eşitlik Modellemesi (PLS-SEM) kullanılarak doğrulanmış ve geliştirilmiştir. Geliştirilen model, MTSM'im benimsenmesinde etkili olan faktörlerin açıklanması amacını taşımaktadır.

Anahtar Sözcükler: Model Tabanlı Sistem Mühendisliği, Sistem Mühendisliği, Benimseme, Savunma Sanayi, Teknoloji Kabul Modeli

To My Family

ACKNOWLEDGMENTS

First of all, I would like to express my gratitude to my supervisor Prof. Dr. Sevgi Özkan Yıldırım, who has been kind enough to provide me with guidance and assistance throughout the duration of preparation of this thesis.

I would also like to express my thanks to all of the engineering practitioners that have participated in both the pilot and final study, for their cooperation and aid in the process of gathering data for the purposes of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
ARCADIA	Architecture Analysis & Design Integrated Approach
ASPEC	Asia-Pacific Software Engineering Conference
AVE	Average Explained Variance
BAE	British Aerospace
BKCASE	Body of Knowledge and Curriculum to Advance Systems Engineering
CA	Cronbach's Alpha
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CFA	Confirmatory Factor Analysis
CIRP	International Academy for Production Engineering
CONOPS	Concept of Operations
CR	Composite Reliability
CSE	Complex Systems Engineering
DBSE	Document-Based Systems Engineering
DMSL	Design-Specific Modeling Language
DOI	Diffusion of Innovations
DOD	Department of Defense
EFA	Exploratory Factor Analysis
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FAMOUS	Functional Avionic Model Oriented Usage
GST	General Systems Theory
JPL	Jet Propulsion Laboratory
IBM	International Business Machines Corporation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineering
IFAC	International Federation of Automatic Control
INCOSE	International Council on Systems Engineering
INSEAD	Institut Européen d'Administration des Affaires
ISO	International Organization for Standardization

MBSE	Model-Based Systems Engineering
METU	Middle East Technical University
MIAMI	MBSE Infusion and Modernization Initiative
NASA	National Aeronautics and Space Administration
NCOSE	National Council on Systems Engineering
OMG	Object Management Group
OOSEM	Object-Oriented Systems Engineering Methodology
OR	Operations Research
ORMS	Operations Research and Management Sciences
OSIRIS-Rex	Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer
OST	Open Systems Theory
OWL	Web Ontology Language
PLS-SEM	Partial Least Squares – Structural Equation Modeling
RFI	Request for Information
ROI	Return on Investment
SDD	System Design Descriptions
SA	State Analysis
SE	Systems Engineering
SEPAT	Systems Engineering Principles Action Team
SRMR	Standardized Root Mean Square Residual
SRS	System Requirements Specifications
SSM	Soft Systems Methodology
SOI	System of Interest
SoS	System of Systems
SOSE	System of Systems Engineering
SysML	System Modeling Language
TAF	Turkish Armed Forces
TAFF	Turkish Armed Forces Foundation
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
UTAUT	Unified Theory of Acceptance and Use of Technology
UK	United Kingdom
UML	Unified Modeling Language
WIPO	World Intellectual Property Organization
WW2	World War II

CHAPTER 1

INTRODUCTION

The earliest and comparably competent efforts that were made towards defining the "system" concept, as more notably referenced among contemporary sources, were formally started following the World Wars, with the introduction of General Systems Theory (von Bertalanffy, 1950). In this frame of reference, the term "system" was broadly used as a complex notion that consists of regularly interacting or interrelated elements with distinct characteristics. However, the general behavior of the overall system may differ from the characteristics of these isolated parts in a way that may present itself as "new" or "emergent.”

The belief that the behavioral aspects of the complex can be deducted from the individual properties of the parts that compose them and the relations between these parts has led to the inception of the interdisciplinary study field of systems theory. The aim was to determine the common aspects and laws of systems operation between different areas irrespective of the system's domain of origin, whether it be physics, biology, neurology, or psychology, and in some way generalize and model them. This stems from the fact that similar concepts regarding a system's behavior were often observed in fields of research that were previously believed to be distinct. These recurring themes of structure, behavior, emergence, and state are found to be common across systems in different fields.

Systems theory sought to narrow the gap between sociological and the so-called "classical" sciences by, among other things, introducing the concept of organization and wholeness to conventional physics. In this line of thought, another vital aspect of the general systems theory would be the incorporation of "organized complexity" into modern science in a way that was juxtaposed with Weaver's work in "Science and Complexity" (Weaver, 1948) and Norbert Wiener's establishment of Cybernetics (Wiener, 1948) as a discipline.

System science, following the evolution of different system theory viewpoints, was then largely popularized (BKCASE Editorial Board, 2016) with the growing need to explain and model increasingly complex systems, mostly due to the rapid advances in technology that dominated the post-war world. Notable concepts like Operations Research (Churchman, Ackoff, & Arnoff, 1950), Systems Analysis (Paxson, 1950), Hard and Soft Systems Thinking (P. Checkland, 1981), and Organizational Cybernetics (Beer, 1959) have started to unfold along this period.

In time, in correlation with the recent developments on systems theory, approaches in the application of these theories in the field of applied sciences have also begun to develop in organizational themes by the practitioners of their respective fields (von Bertalanffy, 1973). Early adopters of these methodologies have implemented systems theory into "engineered systems," a functional combination of elements with an inherent organized complexity. The practice was therefore called System Engineering (SE).

The term system engineering refers to the interdisciplinary branch of engineering where fields of engineering design and management are intertwined, mostly utilized in order to contrive and govern complex systems. Such systems can be thought of as an aggregation of small-scale technical constituents joined together with the purpose of fulfilling a variety of tasks. Designing and managing such systems unveils several challenges for the design engineer, as well as the systems engineer, especially when considering (INCOSE, 2015) that these systems have become increasingly complex and sophisticated over the years. This is mostly due to the inherent consequences of having to build a common ground between various disciplines that encompass technical components, human factors, and organizational issues. Therefore, contemporary challenges of designing and managing systems, as well as the increasing complexity, necessitated the usage of new methods that were previously unavailable to document-based engineering practices.

Studies related to Model-Based Systems Engineering (MBSE) have been ongoing since the 1960s (Haskins, 2011). However, the subject gained pace owing to the contributions of A. Wayne Wymore, who also coined the term, with the mathematical framework of MBSE (Wymore, 1993) in the book entitled "Model-Based Systems Engineering: An Introduction to the Mathematical Theory of Discrete Systems and the Tricotyledon Theory of System Design." In 2007, the International Council on System Engineering (INCOSE) had initiated the MBSE Initiative (Estefan, 2008), formally acknowledging the practice, thus fostering its systemic growth. In INCOSE Systems Engineering Vision 2025 (INCOSE, 2014), MBSE has been identified as an emerging approach, though still being in its early development phases. Full-fledged transition to the model-based approaches offers efficiency, but the challenges to adopting remain.

Many organizations (BKCASE Editorial Board, 2016) are in the process of adopting MBSE in some manner with the common goal of improving their systems engineering practices, in some industries more widespread than others. Identifying the factors regarding the adoption of these approaches on an industrial level is considered to be a substantial matter, both in organizational and academic viewpoints.

Implementing successful transition of a new technological approach most of the time poses unique challenges; thus, identifying the aspects that may prevent or encourage such initiatives may prove to be most valuable to the organizations that are willing to do so, especially considering the improvements to the system engineering processes that MBSE may provide if the mentioned organizations implement the approaches appropriately. This study, therefore, aims to provide an academic view on the past experiences that were reflected upon through research papers conducted with this topic in mind, with the aim of paving the way for future attempts to implement MBSE and other information technology-related approaches in organizations successfully.

1.1. Background and Motivation

Although efforts made towards transitioning System Engineering into a more model-based discipline on an institutional level are relatively in their infant stages, significant several leading engineering communities have not been hesitant to approach the matter. The adoption of MBSE methodologies was spearheaded in organizations such as NASA (Holladay et al., 2019), BAE Systems (Ferguson et al., 2020), Boeing (Malone et al., 2016), and Thales UK (Bonnet et al., 2015), among others. These primary efforts to adopt MBSE practices and methodologies have shed light on the advantages and challenges of introducing a novel approach into an organizational scheme. A considerable number of studies have been authored to document these aspects, thus acting as sources of know-how. This study offers a substantial review of the literature on MBSE adoption in the industry to identify the challenges and its underlying constructs that may present themselves during the process.

While studies concerning the adoption of such methodologies in industrial scenes have yielded success, the process itself has to be catered to the organization at hand as the competencies and characteristics of the target environment vary significantly. After reviewing relevant literature, this thesis aims to utilize this aggregated information to tailor an MBSE adoption framework to a defense company involved in designing and developing large-scale complex engineered systems. These systems design projects encompass a composition of teams of software, mechanical and production engineers, with system engineer units acting as a mediator.

Within the pretensions mentioned above, the study presented herein offers to inquire about some research questions designated with relation to the current state of MBSE adoption within the defense industry. These main research questions were illustrated below as:

- What is the current state of the adoption of MBSE within industrial organizations?
- How does implementing MBSE into organizational settings benefit the adopters?
- What are the challenges faced by the adopters upon commencing MBSE implementation efforts?

In order to find resounding and assuring answers to these research questions, the following research sub-questions were also pursued along the course of this thesis:

- What is the distribution of the organizations that are in the process of implementing MBSE into their business practices operational areas?
- What are the most prominent MBSE methodologies developed to ease the transition into model-based approaches?
- What are the advantages/disadvantages of these methodologies?

- What would be a solid starting point for organizations looking into commencing the transition into model-based approaches? Why?

A transition from document-based approaches to system models would affect all participants of the design process as well as other stakeholders, thus requiring an active oversight of system engineers. MBSE may be employed in a number of system life cycle activities such as requirement definition, systems design and analysis, functional decomposition, verification, and validation. In increasingly complex systems, these activities may prove challenging to document appropriately.

Development of models that encompass system artifacts may work in favor of system engineers in reducing the inherent complexity, as well as providing a common ground for various stakeholders in terms of system understanding. This manner of a streamlined approach may offer the organization a cutting edge in systems design practices.

1.2. Significance of the Study

This study was prepared with the pretensions of shedding light on contemporary techniques in systems engineering in industrial settings, namely Model-Based Systems Engineering (MBSE) in mind. With this goal, the course of the thesis follows a threefold approach to the subject matter.

Firstly, an appropriate introduction of system theory's origins and its progression along the technological age were provided, along with different interpretations of systems theorists in the topic of managing complexity in social systems. At the second stage, the study focuses on the development of engineered systems and the challenges that practitioners of systems engineering encounter.

Arguments regarding implementing model-based approaches to systems engineering life-cycle activities have been ongoing since the early 1990s. However, competent tools have been developed to address this issue only recently, and they were met with little enthusiasm by the practitioners. An investigation towards challenges met with the adoption of this methodology in practice was provided with real-life examples of successful adaptations in notable organizations that were classified in an orderly manner with the literature review. There are all kinds of sectors with large-scale systems development practices like defense and aerospace industries among these organizations.

At the latter stages of this study, investigative research was perpetrated to identify feasible solutions to the adoption of MBSE in a local defense company employed with developing large-scale complex systems, similar to the examples identified in the literature review.

The significance of this study thus poses itself as a comprehensive research attempt of identifying contemporary approaches, tools, and methodologies of MBSE as employed in organizational settings as well as their respective advantages and disadvantages. This thesis also aims to identify the forces that prevent and promote the adoption of model-based approaches that were previously presented themselves in organizations that have gone through similar struggles, in the form of reviewing academic papers that have documented these efforts. The thesis presents itself as one of the first studies that aim to shed light on systems engineering processes and their resistance to adoption conducted in Turkey, with one of the leading defense industry companies' engineering practitioners actively participating.

1.3. Structure of the Thesis

The top-level workflow diagram that was followed during the preparation of this study is illustrated in Figure 1.

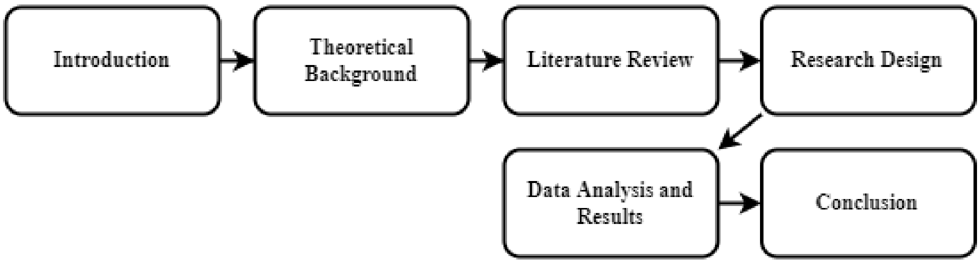

Figure 1: Flow Diagram of the Thesis

The progression of this study hereafter is as follows; the theoretical background of the concepts that are related to systems context and history of systems engineering practices and approaches up to the contemporary trends are discussed in the first part of the second chapter, where a twofold structure occurs. After laying down the definitions of the related concepts in accordance with the literature, an extensive literature review was conducted in order to correctly identify a number of topics that are related to the purposes of the study. The topics include model-based approaches in systems engineering, the adoption of such approaches within actual organizations that utilize some form of systems engineering in practice, along with the tools and methodologies that were developed to fulfill these advances into newer territories. The results of this literature review and the relative categorization of the data that was reviewed preside in Chapter 2.

In Chapter 3, the construction of the research methodology that was followed in order to effectively measure the actual intent of the practitioners regarding adopting model-based techniques and approaches within their respective workflows was discussed. The details of the investigative study that was followed are given. Results of the study and the details of the analysis results were elaborated in Chapter 4. Furthermore lastly, the ramifications of the study were discussed, and possible implications for future studies were evaluated in the last chapter.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

The aggregated results of the preliminary literature research are presented in two parts in this chapter of the study. A detailed overview of systems theory and systems engineering as a discipline is provided in the first part. At the same time, the latter focuses on reviewing MBSE methodologies and approaches as well as providing an extended classification of the adoption of MBSE in real-life industrial contexts.

Throughout this chapter, concepts regarding the inception and evolution of systems engineering and systems theory and the standard practices that dictate the behavioral intention of users when it comes to the acceptance of novel technologies were elaborated, and a general overview of SE processes was provided. The former stages of this study were prepared as a basis for fundamental knowledge on system design, with later sections focusing primarily to research design and application on the topic that has been established thus far.

The idea that MBSE is the next logical step in SE design principles is prevalent throughout this study. In the next chapter, this train of thought is furthered with identifying conventional MBSE methodologies accustomed by real-world organizations through reviews made in the literature. The methodologies mentioned within this thesis' scope bear a particular manner of significance, or they are more widely accepted and used approaches.

Upon investigating contemporary perspectives on prominent MBSE methodologies, the literature review accommodates detailed research on studies related to MBSE adoption efforts in real-world organizations in order to evaluate the current state of affairs regarding the future of MBSE

The second chapter of this thesis study incorporates a systematic literature review to investigate further model-based system engineering and its possible implications to the future of the engineering community and the organizations that employ SE practices. The agenda in doing so mandates exploratory research that encompasses both the current MBSE methodologies that organizations are trying to implement and the challenges that may pose themselves.

Therefore, the extent of this systematic literature research is twofold; in the first part, the study focuses on identifying and evaluating various novel MBSE methodologies and tools presented over the years advertised as effective ways of dealing with complexity that is inherent in large-scale systems modeling. In contrast, the latter aims to shed light on the numerous incentives and challenges that emerge from adopting the model-based approach with documented real-life examples of implementation efforts.

2.1. Evolution of System Theory

Although studies with the aim of developing a "systems approach" were surfaced in the 20th century, concepts regarding the nature of systems and complexity are hardly considered to be contemporary. The reason for the growing need to explain systems behavior may be apparent to the knowledgeable audience; the exponential growth of revelations in natural and physical sciences has led to the segmentation of modern science into a wide variety of disciplines. These isolationist approaches have prevailed in explaining the characteristics of elementary units at first, albeit with the cost of possibly disregarding any environmental effect that may apply to them. Over time, it has become apparent in some academic circles (Pouvreau & Drack, 2007) that these methods fail to explain the notion of "wholeness" and "organization," which are attributed to entities belonging to a system.

2.1.1. General System Theory

The absence of a generalized theory that seeks to explain and possibly model the inherent relationships between parts and processes belonging to an "organismic" construct was apparent to some at the time. Philosopher and theoretical biologist Ludwig von Bertalanffy has sought to address this problem of generalization with the publication of Open Systems Theory (OST) (1950), which was a denouement of its works as early as the start of WW2. The approach has benefited from the placement of its area of origin in the classification of sciences. Biology was at that time conveniently interchanging ideas with both sides of the academic spectrum, physics and chemistry on one side and psychology and sociology on the other. The theory, as credited by its author (von Bertalanffy, 1972); had its inspirations in a wide variety of philosophical trends in European circles; from the likes of perspectivism to German mysticists, even drawing heavily from the adage of Gestalt theory (Köhler, 1967); "the whole is more than the sum of its parts." While demonstrating its constructs on the theme of organismic biology, the theory of open systems advocated for the existence of isomorphisms in an interdisciplinary manner. The appearance of structural similarities in different fields, in theory, made it so that it was immediately applicable across most disciplines.

Although Bertalanffy's primary discourses on general systemology began earlier, the publication of Open Systems Theory and the extensive recognition that was brought to it assisted in his efforts. General System Theory (GST) has been postulated from the need to explain and model principles relevant to all open systems. Contrary to its predecessor, the discipline is more aligned with a logico-mathematical theme than a theoretical one. It focuses on formalizing the concept of "wholeness," which was previously regarded as vague and intangible. Along with being attributed to postulating the theory that comprehensively deals with general systemology, Bertalanffy has also contributed to systems research by co-founding the Society for General System Theory in 1954, along with Kenneth Boulding, Ralph Gerard, and Anatol Rapoport.

2.1.2. First-Order and Second-Order Cybernetics

As contributions towards a foundation for a philosophy of systemology grew in popularity, another prominent transdisciplinary approach to offer a method for the scientific treatment of the system and complexity also loomed in the same breath. Cybernetics, the study of communication, regulation, and control of any system, was elaborated by mathematician and philosopher Norbert Wiener in his 1948 book "Cybernetics or Control and Communication in the Animal and the Machine" (Wiener, 1961). The term was derived from the Greek *kybernetes*, as used by Plato, which translates into "steersman" or "governance." The usage of this term was no coincidence since Wiener and the early cyberneticians' view was also aligned with the originator of the term's focus on the control relations not only in engineered systems but natural systems such as organisms and societies (Heylighen, 2001).

Cybernetics has been incredibly influential on a number of disciplines, namely Game Theory, System Theory, Information Theory, and Control Theory. Although initially focused on functional characteristics of systems and machines that use the information to posit some manner of self-governance, the study field defined many concepts that were relevant to other contemporary sciences, such as autonomy, networks, organization, and complexity. To this end, it was no surprise that early cybernetic thinkers followed up on mathematicizing of general systemology, eventually placing cybernetics as an irreplaceable pillar of systems science.

First-order advocates of cybernetics, such as Claude Shannon, Norbert Wiener, William Ross Ashby, and John von Neumann, have formed the study as a discipline in Macy Conferences proceedings held between 1946 and 1953. These developments were more focused on the observed system and its behavior as a closed-loop (Ashby, 1956), such as the concept of feedback, while the precedents of cybernetic study have distinguished themselves by also considering the observer as another system that is interacting with the observed one with the purpose of modeling it. These researchers are attributed to ushering the second-order approach in cybernetics well into the 1970s.

Cybernetic modeling has become a tool for many of the research fields in the day, and in time many of the core ideas of the area have been adopted by other disciplines, essentially rendering its incipiency irrelevant. Contemporary trending topics such as neural networks, artificial intelligence, complex adaptive systems, and computer science, in general, have borrowed some of their ideas first coined by cybernetics (Sieniutycz, 2020).

2.1.3. Operations Research

The inception of the concept of Operations Research (OR) has been in a military context during the Second World War with the efforts of scientists and researchers that military services have gathered from different disciplinary backgrounds. The aim was roughly to optimize limited war-time resources in airborne, land, and maritime missions by using scientific approaches, which are primarily attributed nowadays as the first applications of systems engineering (Bhunia et al., 2019). The term was originally coined by McCloskey and Trefethen in 1940. After the war, OR teams' successes have already been widely accepted by US and UK military services, inspiring civil institutions to follow suit with OR applications, yet constituting another instance where advances in military technology spearhead public ones.

Techniques and approaches associated with OR encompass a wide array of disciplines, with some repurposed for use in organizational themes such as industry, defense, and government sectors. Departments in expanding organizations such as production, marketing, and finance have become involved in optimization, and modeling techniques originated from OR. To this end, Operations Research and Management Sciences (ORMS) was formed by Russell L. Ackoff and C. West Churchman in 1950 (Churchman & Ackoff, 1951). The approach represented an interdisciplinary branch of applied mathematics and engineering with the intent to improve an organization's managerial decision-making skills. Operations Research adopted an effective use of models in the early phases of problem-solving cycles, as the phases mentioned were listed by (Churchman, Ackoff, Arnoff, et al., 1950) in Table 1.

Table 1: Operations Research Phases

1.	Formulating the problem.
2.	Constructing a mathematical model.
3.	Deriving a solution from the model.
4.	Testing the model and the solution derived from it.
5.	Establishing controls over the solution.
6.	Implementation of the solution to the real-life system.

By the early 1970s, as complexity in industries grew exponentially, criticism towards existing systems approaches that involve mechanical thinking and methodical strategies have emerged in practicing circles, including pioneers of ORMS (BKCASE Editorial Board, 2016). The common view at the time was that a fixed spectrum of solutions and methodologies would not be sufficient to meet the needs of designing contemporary system models due to the holistic nature of real-life problems. Studies regarding the classification of systems and system methodologies have emerged in this period.

2.1.4. Hard and Soft Systems Thinking

Through an era of debate over comparative analyses of systems methodologies in use by OR and systems analysis (Fisher & Walker, 1994), traditional systems thinking that was in effect is influenced predominantly by positivism and functionalism (Mike C. Jackson, 2001) has started to diversify from its origin. The main driver of these changes was increased complexity caused by ill-structured challenges and the belief that human and social aspects of problem situations cannot be dealt with "hard" systems approaches.

Systems thinkers have approached this problem by diversifying existing interpretations of systems behavior to include models that somehow better identify fringes in organizational design that tend to have an inherent sociological aspect. Thus, softer systems approaches have been developed; Organizational Cybernetics (Elphick & Beer, 1981), Soft Systems Thinking (P. Checkland, 1981), and critical systems thinking (Michael C. Jackson, 1985) among them.

Most of the time, these developments had social systems and problems at their focus, armed with a perspective that is ultimately subjectivist when assessing the evaluation of soft systems by the observer. Checkland, in line with other soft systems thinkers at the time, advocated heavily for the importance of different *worldviews* among society and the need to consider the actual intention of the individual in social systems. (Peter Checkland & Poulter, 2010)

The introduction of the theory behind these recent developments in the soft system movement was elaborated in Systems Thinking, Systems Practice by Peter Checkland in 1981, who also detailed a comprehensive rubric of systems methodologies. These classifications are justified at the top level as "hard system methodologies" and "soft system methodologies" that ultimately encompass system design perspectives of the era and onward.

The exposition of the Soft Systems Methodology (SSM) was composed of a seven staged learning process, such that at each interpretive-based step, a connection between real-world situations and systemic thinking has been brought into consideration. These stages bared no interim process in between them but rather circumfluent and concurrent; they can be reiterated until the analyst begins to form structural accommodations of the problem at hand. The process itself adopts a cyclical implementation where each iteration brings in new information relevant to the problem situation. In this case, the problem solver gathers how each stakeholder perceives the problem, lays out classifications of desirable and feasible changes in the system at hand, and tries to define an iteration of the situation that negotiates a common ground between the stakeholders.

Although the originators of the soft systems movement have shown signs of avoiding the means-ends approach of more mechanistic worldviews of the past, systems engineering and project management practices which are mostly known for leaning towards these views, have benefited from the considerations put forward by SSM.

Differing from other systems approaches, some changes in the classical way of thinking that resides not only in Systems Engineering but also in Operational Research and Systems Analysis, among others, to incorporate SSM into SE application were due. Checkland considers individuals' conflicting worldviews as a factor that characterizes all social interactions and argues that they can be organized as a learning system by themselves (Peter Checkland & Poulter, 2010). This way of thinking paves the way to try and build models of these new additions to the systems environment in order to expose its attributes similar to how SE practitioners handle mechanical systems. SSM's holistic process building has brought new perspectives into systems engineering and project management, two disciplines that culminate within organizational schemes. Project management, initially thought to be in striking contrast to systems engineering in terms of practices (Winter & Checkland, 2003), also benefited from softer approaches as problems in real-world situations may present themselves as ill-structured and impalpable at first.

Soft Systems Methodology has persisted in maturing with consecutive research since its genesis, and the progenitors of the theory have improved upon possible shortcomings of the archetype. In Soft Systems Methodology in Action, SSM was separated into two modes as the authors demonstrate their theory in an applicatory fashion. With the newer SSM Mode 2, a vast expansion into political and cultural changes was also considered while the former relatively stayed the same. The approach eventually found its way into the Information Systems domain as a reliable tool (Flood, 2000) for analyzing and explaining the behavior of organizational structures, which are constituted of knowledge-power mechanisms.

2.2. Systems Engineering

Systems engineering (SE) is commonly attributed as an interdisciplinary approach facilitated in order to design and realize product systems that are tailored for the requirements of the user. The revised definition of SE by INCOSE is "a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods" (INCOSE, 2015).

The leading actor affected by the changes in systems approaches is the system engineer, who is tasked with dealing with the various aspects that designing a system may pose. Systems thinking within this context especially becomes critical when dealing with system-specific behavioral factors like emergent properties and complexity, which requires a more holistic approach.

Systems engineering as a discipline may be applied to any size and type of system. However, this fact does not necessitate that they should be blindly applied for the sake of application. Tailoring for the specific product sector or domain may improve the efficacy of these endeavors, requiring a preliminary study to adopt. Nonetheless, SE has been traditionally applied with success (INCOSE, 2015) by industries that develop and sell complex systems with a relatively long life cycle and small production volumes.

The end products at hand are engineered to be either purely technical or socio-technical systems as they may accommodate attributes related to interacting with the environment around them. As these systems of interest grew in complexity, they may exhibit some properties that can be regarded as emergent, ultimately making system design a formidable task assigned to system engineers.

Although the scope of SE does not eventually encompass every single process related to the engineering of the system-of-interest (SOI), since system engineers are tasked with ensuring the successful realization of systems, their operating area coincides with many other disciplines in order to do so. The iterative processes of the SE domain that aim to ensure successful system delivery are embedded into all stages of the system life cycle. The application of SE practices in the industrial context is put to use early in the development when customer needs and requirements for a successful operational concept are defined. The rest of the traditional scope of systems engineering encompasses and is closely related to the conception, design, analysis, verification, and validation stages of the engineered system's life cycle. These interrelations are depicted in various system engineering methodologies and frameworks discussed in the current subsection.

Although a considerable amount of time has passed since the early 1940s, when the discipline is originally postulated (Hall, 1962), SE has gained more relevance since the early 1990s. The operational areas of SE have stayed roughly the same over the years. Nevertheless, they are more concretely defined nowadays with the efforts of numerous international institutions and engineering standards.

In 1990, the National Council on Systems Engineering (NCOSE) was founded by a number of practitioners and representatives from various organizations in the United States. The institution was later renamed in 1995 as the International Council on Systems Engineering (INCOSE) upon receiving a growing involvement from systems engineers abroad and is widely recognized as the most avid contributor to systems engineering approaches worldwide.

System engineers employ a set of SE processes to meet the need to accomplish the development of a successful SOI, independent of its type. These process clusters are generally put to use through a methodological framework based on but not dependent on systems thinking.

As the practice of systems engineering grew in international schemes, more developed principles regarding the application of the course have been postulated. As an example of these efforts, in 2019, the INCOSE Systems Engineering Principles Action Team (SEPAT) has defined a set of hypotheses and principles (Watson, 2019) that attempts to relieve system engineers from some of the burden of their task at hand. There has also been growing interest in identifying new operating fields of systems engineering, such as System of Systems Engineering (SOSE) or Complex Systems Engineering (CSE). Even though systems engineering can no longer be counted as a new field (Sousa-Poza et al., 2015), there is possibly a considerable amount of room for improvement for its range of applicability, methods, and principles. In order to correctly identify which areas and ideas SE practices may revolve around in the future, the premises of this thesis involved a detailed look into contemporary topics in the systems engineering literature. In the following subsections, current trends in SE practices and their origins have been identified.

Contemporary approaches to system engineering practices may employ many borrowed pieces of methodologies from other disciplines. While traditional SE approaches have been known to deliver sufficiently efficacious systems-of-interest afore, room for improvement is always present in these studies as the topic at hand is intangible in more ways than one.

While the common principles of systems engineering as a discipline remain mostly intact, the increased scope of producing systems-of-interest that modern engineering organizations are dealing with necessitates the development of seemingly new approaches. These approaches and methods may pose themselves as entirely unique even though they are merely iterated from the main postulates, principles, and hypotheses of Systems Engineering.

2.2.1 Classification of Systems and Engineered Systems

There are a number of classifications that can be applied to the types of systems that may or may not naturally exist in real life. For example, one of the leading system theorists at the time, Kenneth E. Boulding in (Boulding, 1956), has classified systems into nine types that were further iterated by von Bertalanffy in (von Bertalanffy, 1973) who has attempted to provide such a taxonomy; which was elaborated extensively throughout the author's later works. The taxonomy mentioned is illustrated in Table 2.

Table 2: Main Levels in Hierarchy of Systems

Hierarchical Level	**Description and Examples**
Static Structures	Atoms, Molecules
Clockworks	Clocks, Conventional Machine Structures
Control Mechanisms	Thermostat, Feedback Mechanisms
Open Systems	Cells and Organisms in General
Lower Organisms	Plant-like Organisms
Animals	Learning, Consciousness-Bearing Beings
Man	Self-Awareness, Communication Capable Beings
Socio-cultural Systems	Population of Organisms
Symbolic Systems	Language, Logic, Mathematics, Transcendental Beings

While constituting a reasonable manner of classifying systems that partake in the shared space of physics, this approach fails to coincide with modern system thinking practices like open and closed systems and feedback systems. In time, various other systems theorists have attempted to provide a more comprehensive outlook on the topic of system classification. For example, Peter Checkland, in his study, divides systems into five classes: natural systems, designed physical systems, designed abstract systems, human activity systems, and transcendental systems (P. Checkland, 1981).

SSM approach has successfully identified the differences between natural and designed systems, the latter being the main topic of interest in this study. Designed systems are also referred to as engineered systems defined in ISO/IEC/IEEE 15288 as "man-made, created and utilized to provide products and services in defined environments for the benefit of users and other stakeholders."

Regarding the types of these engineered systems, though, there is no agreed-upon classification. Although, one may infer the type of systems with the knowledge of how the system was designed and the purpose behind procuring such a system. Most of the time, the engineered system is a product designed for the use of some end-user or other stakeholder, as per the definition of the system. Therefore, these systems can be called product systems, while other use cases may include information-driven services or both at the same time. Thus, engineered systems can be classified as product, service, enterprise, and system-of-systems.

The main distinction between these systems comes from the designed use cases and scenarios. For example, a product system may include both hardware and software elements directly delivered to the hands of the user to conduct some functionality, while a service system may be limited in such aspects in order to provide some unique feature to the customer. An enterprise system, though, may include other environmental aspects required to operate, like people, processes, and organizational context.

Designing and applying the aforementioned system contexts to an end product or service is usually conducted through many predesignated approaches that systems engineering practitioners employ the required paradigm. Application of the systems approach that the engineers should undertake thus poses importance to the engineered system's outcome.

2.2.2 System Life-Cycle Activities

Although not always clearly defined, every engineered system inherits a life cycle where different stages of design, production, and post-production processes can be inferred by the designing engineer. In order to attain success in managing the orderly development of the SOI, system engineers are inclined to outline the distribution of the technical workforce through each defined stage of the life cycle.

The engineered system undergoes predicted life cycle activities owing to the actions performed by individuals with related technical expertise, while the designing system engineer orchestrates the succession of these actions.

There are various sets of generic life cycle stages that are adopted and defined through experience by different organizations, although these frameworks may not always be directly apparent or applicable to emerging system needs. System management principles require practitioners to be vigilant with evaluating system effectiveness and performance and preparing and conducting processes that mitigate risk at each consecutive step. Developing such a framework requires a holistic perspective that considers each of the stakeholders' needs and requirements for successful operation.

Figure 2 aims to demonstrate an overview of systems engineering activities based on their stages of the system life cycle; a generic flow of life cycle processes and their respective outputs of an engineered system has been shown. In this case, the system's lifeline is highlighted in five stages; concept, development, production, utilization & maintenance, and retirement phases.

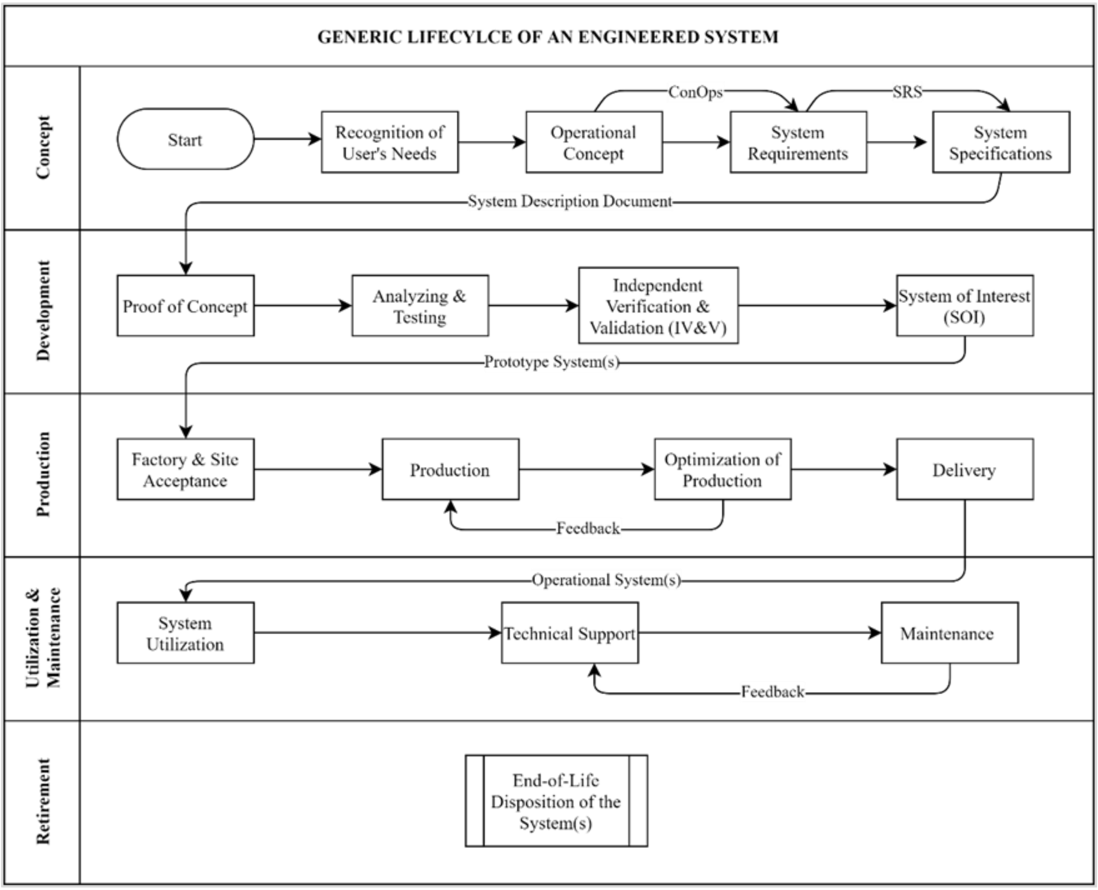

Figure 2: Generic Lifecycle of an Engineered System

In the conceptual phase, the customer/user/stakeholder's necessities are aggregated into concepts of a system of interest. The architecture and relative specifications of the SOI are loosely defined at the start of the project, but still, as the concept phase progresses, user requirements and their operational projections become more evident and distinct as end-users and designers agree upon a conceptual design. This accord between the project stakeholders is traditionally reflected upon an Operational Concept (ConOps or OpsCon) document in document-based systems engineering approaches.

Upon reaching a certain level of maturity in requirements specifications, the design team advances into delivering these requirements on the conceptual system. At this stage, exploratory research in related fields may be required, not only for the accurate realization of the concept but also for the precise projection of early cost and schedule estimations of the overall project. These research efforts aim to shed light on the exact problem space to prevent unwanted iterations of the conceptual design. Emergent issues that may not be immediately apparent in system design threaten projected outcomes of the design phase; therefore, the designers must address them appropriately.

The results of exploratory research are used to complement the clearly defined requirements of the operational concept in the System Requirements Specifications (SRS) document. The System Design Specifications (SDD) document is regarded as a formal declaration of the proof of concept by the design team addressed to the stakeholders of the project. Concurrency between these stakeholders holds vital importance, and it usually follows a pattern where general conjunction is weak at the project's inception, only to converge at later phases. Hence, any disorder in the early life cycle plays an infamous part in delivering efficient and capable projections.

The development stage of an SOI's life cycle necessitates prior requirement definitions to be concluded. Its general aim is to realize the system through multiple hardware and software development and integration steps. These development efforts may demonstrate a layered approach, where system elements are constructed as subsystems overseen from the top system level. Subsystems are also treated and act as systems themselves, with their functions and attributes contributing to the system's behavior in some way. The result of this generic life cycle is generally a prototype SOI(s), though the system's actual manufacturing processes are typically attributed to the production phase.

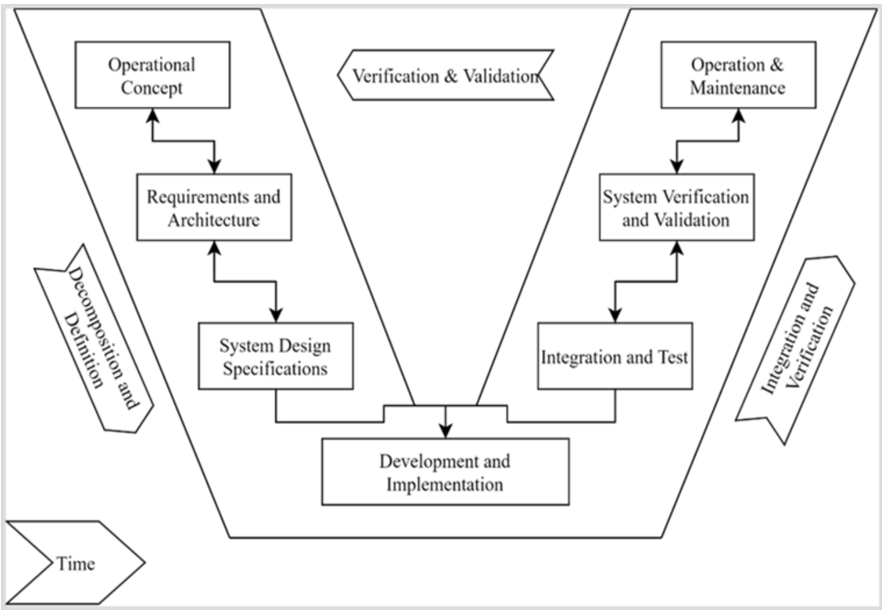

Figure 3: V Model in Systems Engineering

The production stage brings forth new challenges to the engineering organization, where a number of hardware and software issues that did not emerge in prototype models may appear, along with modifications to production processes needed to ensure streamlined manufacturing. These modifications are also conducted to reduce production costs, rearrange supplier vendors, or enhance system capabilities.

Units produced might undergo several tests that assess the qualification and the validation of the final output throughout production steps. The content of these tests may vary according to the operational needs of the stakeholder and is usually denoted as requirements of a pre-determined standard. Such adherence to requirements may include electromagnetic compatibility (EMC) & electromagnetic interference (EMI), vibration, shock, dust, and environmental stress tests.

After the acquisition of the SOI by the stakeholder through acceptance tests, the system is delivered for the use of the customer. At this operating stage, communication with the user does not secede; on the contrary, support mechanisms within the organization are put to use to ensure continued use and maintenance of the SOI.

Modifications according to these directions may carry like previous stages, with topics including solving supportability problems, improving reliability, and maintaining long-term service. These iterations may continue right up to the retirement phase; the terms of disposability should be planned back in the concept stage.

2.2.3 Model-Based Systems Engineering

Elucidating a system's possible behavior and boundaries with the utilization of models is a commonly visited approach in systems thinking. Its origins date back to the early formalized methodologies that can be considered as progenitors of systems theory such as Cybernetics and General Systems Theory. The benefits of doing so were apparent to the practitioners, who adapted modeling and simulation as primary tools in understanding system design.

System models act as abstractions of a real-world system, which allows system designers to effectively predict and sculpt system behavior and properties without actually having to develop the SOI to some degree. This advantage is particularly noticeable when dealing with increasingly complex systems, as prominent utilization of these methods may reduce budget and schedule overruns in system design project schemes.

Modeling and simulation may play a role in all stages of a system of interest's life cycle, although gradually losing weight after the earlier stages. System engineers may conduct several life-cycle activities within models themselves, which generates data that previously was not available to the analyzing designer. These methods do not only directly serve system engineers that conduct them, but they are also invaluable tools in conveying system understanding to the other stakeholders of the project. Unity in understanding between the stakeholders plays a powerful role in designing exceptional systems; as Conway's law suggests, "any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure" (Conway, 1968).

System engineering practitioners to this day have relied primarily on document-based approaches where existing system design methodologies implicate the use of documents as vessels of information between stakeholders throughout development phases. The application of this approach generates a significant amount of information regarding the attributes of an SOI from different perspectives documented in order to preserve and convey them.

While possible motives to use system modeling practices is apparent to system engineers that utilize them in life cycle processes since the introduction of the discipline, a formalized approach that places models as a primary artifact in system design were found lacking as systems and system of systems (SoS) grew in complexity. This approach took the form of Model-based systems engineering (MBSE), which was coined by Wayne Wymore in 1993 in his book by the same name (Wymore, 1993). Wymore has postulated several mathematical frameworks that encompass system design processes and provide foundational work for the application of model-based design approaches to systems design.

Although fundamentals for a comprehensive model-based approach in contemporary system design were laid out in the 1990s, the application of these approaches was not widely recognized by organizations that practice systems engineering until recent years. The introduction of MBSE as a formal approach in dealing with systems design challenges by INCOSE in the Systems Engineering Vision 2020 in 2007 has been attributed to this increase in popularity.

The INCOSE defines Model-based systems engineering as "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing through development and later life cycle phases" (International Council on Systems Engineering (INCOSE), 2007).

In organizations that employ MBSE approaches in system design, a large portion of the information related to the system is aggregated and stored in the main system model or a set of models, contrary to traditional model-based approaches. The system model acts both as the primary artifact that defines most of the SOI's attributes and as leverage used by the designing engineer with the aim of optimizing and improving system life cycle processes that are being conducted.

The degree of dedication to model-based approaches throughout design efforts is related to the current willingness to employ MBSE to its full potential. These improvements in the design efforts may be composed of enhancements in all generic life-cycle steps previously discussed in the former subsection, such as requirements elicitation, design, analysis, and verification and validation activities.

As the system designers progress through the stages of development, documentation regarding system activities may lag behind and become inconsistent over time (Madni & Sievers, 2018). These degradations are antithetical to model-based approaches, where an abstract system model ultimately becomes more robust over numerous iterations throughout the SOI's life cycle. Consistency of models representing system abstractions during these activities requires a predefined set of tools, methodologies, and vocabulary between disciplines.

2.3. Technology Acceptance Models

The following subsection provides brief introductions to some of the most prominent technology acceptance models that preside within the relevant literature.

Technological advancements evolve seemingly endlessly, and theories that are involved with forming relations between certain concepts and constructs aim to predict and analyze the possible behavior of the intended users of such technologies to gain some leverage in shaping the tech of tomorrow.

From a business standpoint, as technologies evolve, the changes brought with them simultaneously create challenges and offer opportunities to those seeking to implement them into their business model. These factors, such as the availability of the technology, convenience, consumers' need, and security (Lai, 2017) may be perceived as positive or negative and thus affect the overall adoption and implementation of the said technology. Hence, the need to properly analyze and predict these effects and factors has submerged in Information Technology.

This study has included several such theories that aim to do this exact thing, with a perspective elucidating the way forward. A review of such theories and their respective models was deemed essential as the purposes of this study preferably require assistance from a proven approach for forming the framework of the MBSE adoption model that the study aims to propose.

2.3.1. Theory of Diffusion of Innovations

One of the earliest prominent researches made towards explaining the public acceptance of novel innovations was proposed by Everett M. Rogers, with his work entitled Diffusion of Innovations (DOI) (Rogers, 1995). The theory, having been established in the late 1960s, proposed a formulated approach to research having similar purposes. The aim, according to Rogers, was to establish some sort of a framework for researchers that intends to explain innovation acceptance and adoption. The theory explicates "the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 1995).

Figure 4: Diffusion Curve of Innovations

DOI refers to the speed and overall acceptance of innovations through time by the masses as "diffusion," which is reached after subjects go through several stages, including understanding, persuasion, decision, implementation, and confirmation. The theory also develops the S-shaped adoption curve, which categorizes the users in terms of a chronology in which they accept the mentioned technology. The curve is illustrated in Figure 4.

The study was appropriated into IS literature as the research areas have converged, and some of the concepts preliminarily elaborated within DOI have evolved into other, similar theories, and some of the premises that the research has made are still in use today (Lai, 2017).

2.3.2. Theory of Reasonable Action

The Theory of Reasonable Action (TRA) has become one of the most salient hypotheses that are used throughout literature that aims to model the relationship between different sociological and physiological constructs that define the overall “attitude” as the evaluation of the technology from the standpoint of the individual in question, and “behavior” as the outcome of these attitudes and intentions (Fishbein & Ajzen, 1975). The exact topology of these constructs and how they relate with each other within the proposed theory are shown in Figure 5.

As shown from Figure 5, Fishbein and Ajzen have evaluated constructs such as beliefs and intentions as effective against the overall attitude towards behavioral intention to adopt the technology or innovation in question, which normative and behavioral beliefs were accommodating a critical role. Apart from attitude, a second factor was introduced that was aptly named subjective norms, which dictate the individual's view according to others that preside over their immediate community.

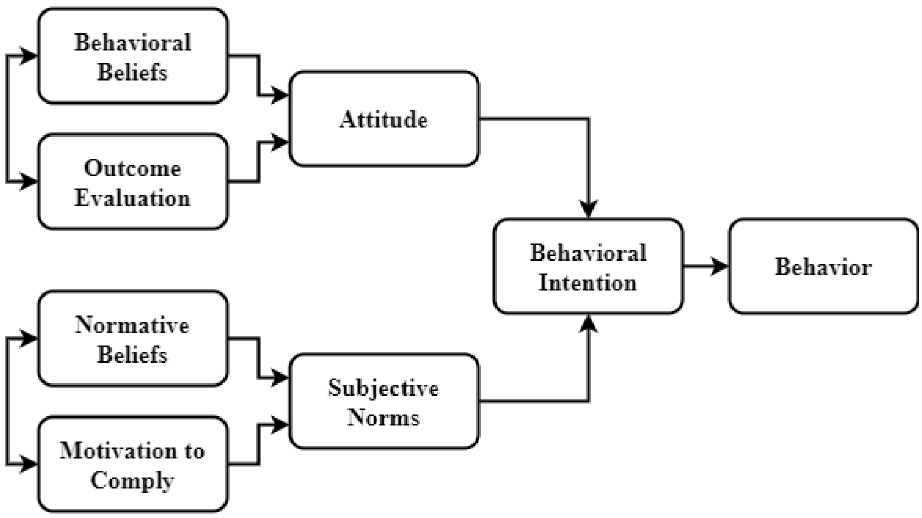

Figure 5: Theory of Reasonable Action

2.3.3. Theory of Planned Behavior

Following the introduction of TRA, Icek Ajzen has developed the Theory of Planned Behavior (TPB), which proposes significant revisions over the prior. Although the first two factors, namely subjective norms, and attitude are the same, Ajzen has included a third factor named perceived behavioral control, which aims to explain the perceived limits of the user's behavior (Ajzen, 1991).

External factors, such as availability, usefulness, and readiness of the technology, are subconsciously evaluated by the individual as it negotiates possible barriers to adopting new technology. The effects of these constructs are illustrated in Figure 6.

As seen by Ajzen, the theory of planned behavior is an extension of the theory of reasoned action, “made necessary by the original model’s limitations in dealing with behaviors over which people have incomplete volitional control” (Ajzen, 1991).

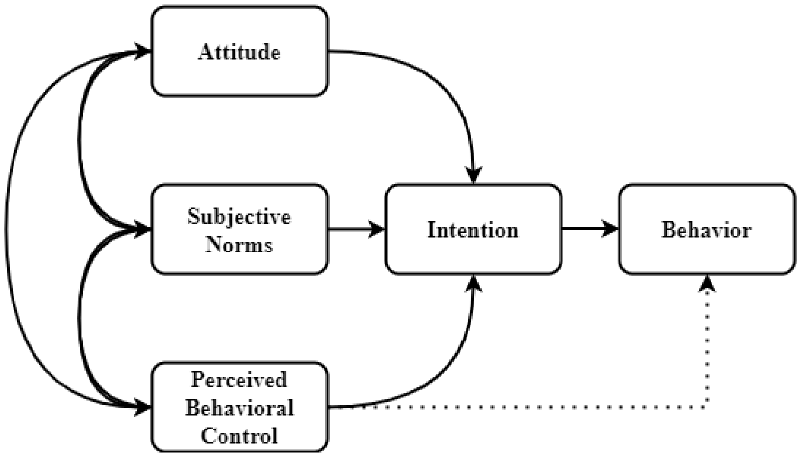

Figure 6: Theory of Planned Behavior

The model constitutes a function of beliefs and salient information that ultimately decides on the outcome of the individual’s behavior. These three types of beliefs, namely behavioral, normative, and control, were distinguished as pillars of the individual’s attitude formation.

2.3.4. Technology Acceptance Model

The TAM model developed by Davis is the most used framework in predicting information technology adoption (Lai, 2017), intending to help researchers and practitioners worldwide distinguish why technology or system that comprises the topic of research may be acceptable or unacceptable by its potential users.

TAM was first coined and introduced by Fred Davis in 1986 for his doctorate proposal. The theory was initially perpetrated as an adaptation of TRA to model the acceptance of the individual regarding information systems and technologies (Davis, 1989).

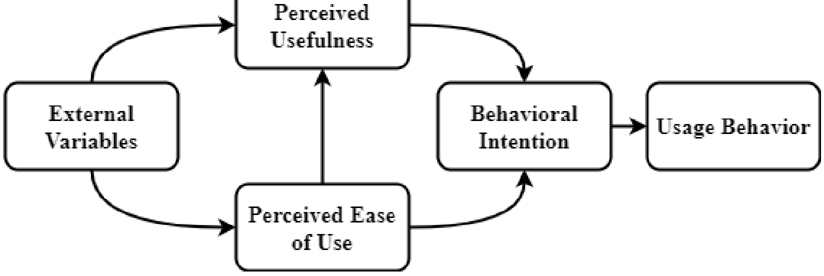

Figure 7: Final Version of Technology Acceptance Model

In 1989, Davis utilized TAM to explain the behavior of potential computer users with the help of theorized general determinants. The basic TAM model included and tested two beliefs, perceived usefulness and perceived ease of use (Lai, 2017). These salient constructs preside over the belief system that determines the overall behavioral intention of the potential user. Perceived usefulness was defined as the subjective likelihood that the targeted system or technology may be helpful, and perceived ease of use dictates the impression of the user that the innovation in question may be easy to use. TAM has also included external variables in relation to these two belief constructs, which may vary according to the technology.

Many versions of TAM have been brought forth since its initial instigation on the IS literature, with the predecessors conveniently named TAM2 and TAM3. Venkatesh and Davis formulated the final version of TAM in 1996 after the assertion that both belief constructs directly influence behavior intention, which has alleviated the need to define an attitude factor (Venkatesh & Davis, 1996). The formation of the constructs and their respective relations with regards to these belief constructs as illustrated in Figure 7.

The theory has been widely used to predict user acceptance and the widespread use of the technology that primarily focuses on perceived ease of use and usefulness. With the addition of external variables, researchers are left with the freedom to decide which factors may be influential in forming the overall belief of the users, based on their respective judgment on the matter and academic proof, such as literature reviews and measurement scales.

2.3.5. Unified Theory of Acceptance and Use of Technology

The model known as the Unified Theory of Acceptance and Use of Technology (UTAUT) was developed by Venkatesh, Morris, Davis, and Davis in 2003. The authors have studied and repurposed previous models and theories to propose a unified, general model for the acceptance and use of technology.

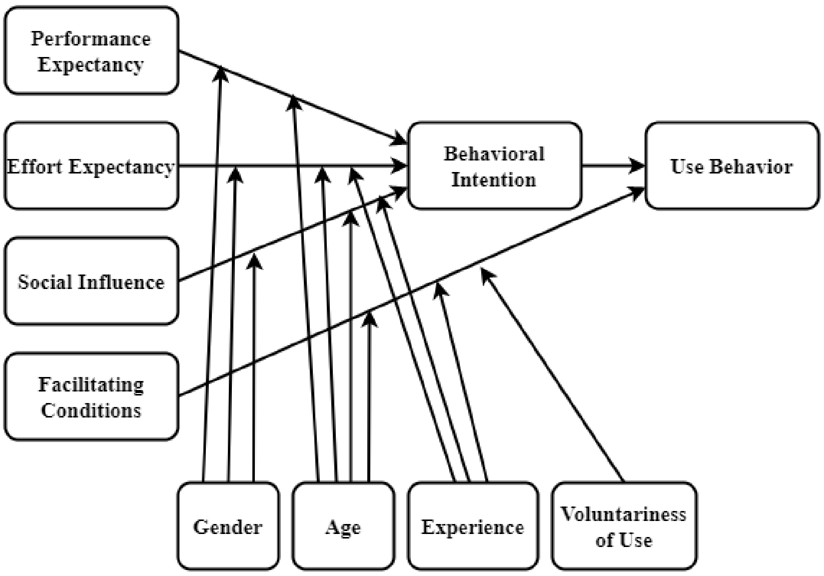

Figure 8: Unified Theory of Acceptance and Use of Technology

The origin of this theory was that "the researchers are confronted with a choice among a multitude of models and find that they must pick and choose constructs across the models, or choose a favored model and largely ignore the contributions from alternative models" (Venkatesh et al., 2003).

Within this model, perceived usefulness, extrinsic motivation, job-fit, relative advantage, and outcome expectations were gathered to be expressed as a singular construct named performance expectancy (Lai, 2017). The attention to other models has continued to be emphasized along with the model, with constructs now being purposed for explaining a multitude of factors identified in antecedent theories.

In order to formulate and validate their model, the authors conducted longitudinal field studies at four organizations to empirically compare the eight models brought to the study. All of the scales that have been used in previous theories were also adapted to this field study, providing an adequate view of the current viewpoint of the users. The result was that the seven constructs, shown in Figure 8, were in direct effect with the intention or usage, with gender, age, and experience providing some manner of support as moderators to these relations.

2.4. Systematic Literature Review Design

Performing reviews of literature that can be accepted as scientific studies necessitate the establishment of the ground rules to be followed upon conducting the research prior to the actual execution. The preliminary planning of the review starts shortly after coming to terms with the topics that will be investigated within the extent of this study, and it includes the definition of review methods and tools.

In this subsection, the scope of these planning efforts will be elaborated, along with the parameters of which the study is conducted, including research questions, search criteria, keywords, probed databases, and requirements for the validity of the results. These aforementioned identifications of the research, if clearly defined beforehand, allow the review to attain an intellectual, persistent property while accurately taking a snapshot of the related studies, which would ultimately contribute to the purposes of this thesis.

Within the premises of the literature review at hand, two main topics related to model-based approaches in systems engineering were investigated in order to correctly relay the scope of efforts that were exerted presently on the topic. The following subsection marks the start of this two-step approach, which focuses on identifying contemporary tools and methodologies that are utilized in order to accommodate model-based approaches in systems design within industrial and academic domains. A number of research papers were selected in line with this aim, documented within this study after a purposeful curation that remains true to the focus of this study.

The penultimate subsection within this chapter is dedicated to the documentation of the efforts to investigate the implementation of model-based approaches in the industry in terms of their initial adoption mechanics and the possible advantages and challenges of these expeditions identified by previous studies. Pinpointing these effects, whether they carry beneficial or adverse properties, may prove increasingly crucial to the successful adoption of MBSE in various industrial circles. The transformation of the adoption trends through the years in these leading industries is investigated herein. The elicitation that the experience and perception of MBSE adopters may elucidate the future of model-based approaches in systems engineering practicing spheres, ultimately representing the current stance as a starting point for future endeavors.

The last subsection of this chapter discusses the findings of the literature review that was conducted in two parts and illustrates them in an orderly manner for a clearer view. The conclusion of the review and its findings bear significance for the rest of the study, as the survey onward was designed with the data extracted within the premises of this chapter. In order to abstain from redundancy, search criteria and exact keywords that were used for the purposes of this review were given in their respective subsections and will not be included here. The workflow followed during the reviewing process is discussed hereafter, and it can also be found illustrated with the help of a flowchart which can be seen in Figure 9.

Figure 9: Literature Review Workflow

The review was conducted within numerous online publishing platforms that accommodate journals in the following associated areas; engineering, systems engineering, system-of-systems engineering design, technology adoption, and MBSE, along with others. The search criteria and the range for the time of the publication of the relevant articles have been designated in order to accommodate a valid search space. Relevant articles and reviews have been found in the following databases: IEEE Xplore, Science Direct, Springer Link, Google Scholar, Web of Science, Sage Journals, and Mendeley. Some online journals, more than others, have supplied materials more pertinent to the purposes of this research.

In order to portray a more current perspective on the related topics, the scope of the review was defined through some parameters. The study takes into consideration works that were published in journals and conference papers between the years 2008 and 2021. Book chapters and grey papers related to the topic were discarded upon initial search, and only published works were included. The results of these classifications were depicted in graphs and charts in their respective subsections.

The initial vetting of the resulting papers was carried out by reading through the abstracts and the primary thought processes of the papers that had come up after searching for the keywords in the aforementioned databases. Papers that were published before 2008 were immediately discarded, along with papers that were restricted even with METU's institutional access. Papers that may have harbored the keywords that were used, however failing to address the purposes of the review, were also discarded. Initial searches have yielded approximately 180 to 200 articles, which were reduced to nearly half that number after this vetting process.

2.5. Model-Based Systems Engineering Methodologies

The scope of this part of the literature review accommodates various perspectives of leading MBSE methodologies and tools identified and evaluated. An overview of the research questions that are aimed to be answered with the help of this research is provided hereafter in Table 3.

Table 3: Research Questions / MBSE Methodologies

No.	Research Questions
Q1	What are the most prominent MBSE methodologies developed to ease the transition into model-based approaches?
Q2	What are the advantages/disadvantages of these methodologies?
Q3	What would be a solid starting point for organizations looking into commencing the transition into model-based approaches? Why?

Most well-known methods and tools were designated as a result of this research based on their appearances in the published literature. Description and identification of these papers were provided, along with detailed explanations of the most referenced methodologies among the investigated papers.

An analysis of methods used and their advantages and disadvantages was conducted after reviewing these papers, and an overview of dominant methodologies among those that were investigated was given in order to provide added value to the literature review. At the time this study was prepared, the transition to MBSE is an ongoing process for some organizations, and there are now multiple ready-for-use tools available to the companies that are willing to adopt, although mass acceptance of these methodologies apparently requires more than employing a selection of tools.

In order to accommodate related works published as journal papers and conference proceedings, a series of combinations of keywords were used in the previously designated databases' search engines. These combinations and their respective Boolean operators utilized for the purposes of this part of the literature review can be seen in Table 4.

Table 4: Keywords Used for Reviewing Databases / MBSE Methodologies

Keyword #1	Boolean Operator #1	Keyword #2	Boolean Operator #2	Keyword #3
"MBSE"	AND	"methods"	OR	"tools"
"MBSE"	AND	"methodologies"	OR	"frameworks"

Table 4 (cont.): Keywords Used for Reviewing Databases / MBSE Methodologies

“Model-based”	AND	“systems engineering”	AND	“methodologies”
“Model-based”	AND	“systems engineering”	AND	“tools”
“Model-driven”	AND	“systems engineering”	AND	“methodologies”
“Model-based”	AND	“systems engineering”	AND	“toolset”
“Model-driven”	AND	“methodologies”	OR	“methods”
“Model”	AND	“systems engineering”	AND	“methodologies”
“SysML”	AND	“methodology”	OR	“design”
“Model-driven”	AND	“engineering”	AND	“approach”
“SysML”	AND	“approach”	OR	“modeling”
“OOSEM”	AND	“model”	OR	“approach”

It is important to note that, in order to provide a more comprehensive view of the topic of prominent MBSE methodologies and toolsets, keywords used in this searching process were expanded to accommodate the names of some prominent tools used in model-based design such as SysML and OOSEM.

2.5.1. Classification of MBSE Methods & Tools

Within the context of this section, a total of 25 papers that have been selected from various databases published between 2008 to 2021 have been reviewed.

From these 25 selected works, three were published as conference proceedings, while the vast majority were selected from journal articles. Articles that were parts of conference proceedings were published in conferences patronized by the International Federation of Automatic Control (IFAC) and The International Academy for Production Engineering (CIRP). The majority of journal articles were also published by IFAC and CIRP, INCOSE, IEEE, and Computer Science, along with others. 88% was from journal articles, while the rest were conference proceedings.

Definitions of methods, methodologies, tools, and toolsets differ in varying degrees across reviewed papers, which may result in false presumptions in evaluating the efficacy of these entities. Therefore, clear definitions of these concepts should be made within the context of this study prior to the expression of the results.

An illustrative chart that depicts this classification based on the publishment year can be seen in Figure 10, and a running aggregation of the studies according to the year was also shown in Figure 11.

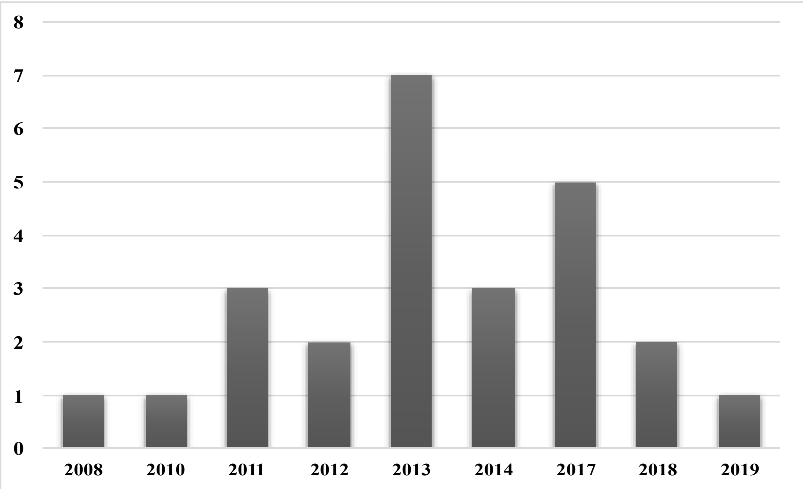

Figure 10: Reviewed Studies by Year

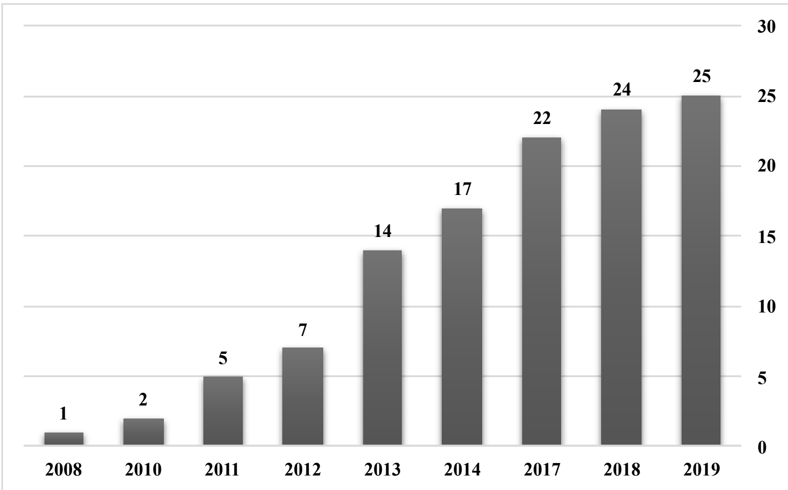

Figure 11: Accumulated Number of Studies Reviewed

An aggregated summary of the methodologies, methods, and tools used within the premises of these studies, along with their respective domains of application as identified by the studies, are shown in Table 5. It is worthwhile to note that even though an overview of these model-based approaches was presented, there are important distinctions to be made before reaching any conclusions about which ones are more prominent or popular than others.

In his survey of MBSE methodologies patronized by the INCOSE MBSE Initiative (Estefan, 2008) addresses this aforementioned disarray in the exact definitions of these related concepts. To quote, a methodology can be defined "as a collection of related processes, methods, and tools" and is essentially a "recipe and can be thought of as the application of related processes, methods, and tools to a class of problems that all have something in common."

Table 5: Reviewed MBSE Methodologies and Toolsets

Method	# of References	Application Domains
SysML-based Methodologies	11	Manufacturing System Planning Validation & Verification Mechatronic Systems Architectural Design Renewable Energy Systems Aero-Engine Product Development Product Lifecycle Management (PLM)
IBM Rational Harmony for SE	2	Integrated Systems Development
Web Ontology Language (OWL)	1	Semiconductor Supply Chain Planning
Business Process Modeling Notation (BPMN)	1	Business Processes
Domain-Specific Modeling Language (DMSL)	2	Self-adaptive Systems Requirements and Functional Architecture
Object-Oriented Systems Engineering Methodology (OOSEM)	2	Analyzing Needs
Vitech MBSE Methodology	2	Source Requirements Modeling Verification and Validation
JPL SA Analysis	2	State Modeling Generating Documents and Reports
Dysfunctional Behavior Database	1	Reliability Engineering

Within the context of engineering disciplines, a methodology is referred to as a concept that encapsulates entities referred to as methods and tools. It is essential to consider that these definitions are consistent within the premises of this literature review as the methodologies presented in Table 5 and within the following section have distinct qualities that distinguish them from others in ways more than one.

From the classification depicted in Table 5, it can be deduced that Object Management Group's (OMG) System Modeling Language (SysML™) was the most referenced modeling language tool among the reviewed papers. Although it can be used as a standalone tool to model system architecture and behavior, other methodologies such as the INCOSE Object-Oriented Systems Engineering Method (OOSEM) also facilitate using this tool under the hood.

The fact that SysML can be used both as a modeling language by itself or as a part of a broader spectrum of processes belonging to a methodology has necessitated for it to take part in this classification while also being the reason for its high turnout rate. In the next section, the structure of the relationship between these tools and concepts will be discussed in greater detail. The distribution of referenced methodologies is illustrated in Figure 12.

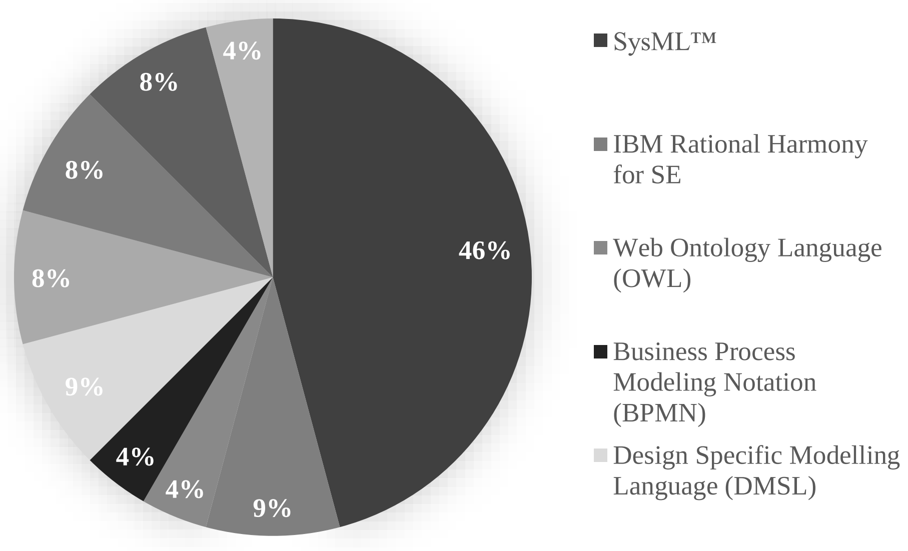

Figure 12: Distribution of Referenced Tools & Methodologies

While there are different methodologies developed in order to meet the developer organization's specific needs, a sizeable portion of the papers utilize SysML as the primary artifact of the developed methodology, furthering the emphasis of the modeling language to those who are looking into implementing model-based approaches to systems design processes.

2.5.2. *Overview of Results*

A convenient stepping stone in exploring contemporary methodologies that are in use in cutting-edge technological organizations is found to be Jeff A. Estefan's survey of MBSE methodologies. Within this survey, Estefan states that "a methodology can be defined as a collection of related processes, methods, and tools. A methodology is essentially a "recipe" and can be thought of as the application of related processes, methods, and tools to a class of problems that all have something in common" (Estefan, 2008). The paper outlines clear distinctions between processes, methods, tools, and methodology. In this survey, not only several contemporary MBSE methodologies that are commercially available are mentioned, but it also includes a new methodology that has been developed at NASA's Jet Propulsion Laboratory (JPL). Within their field of study, JPL has been working on developing and applying MBSE to various large-scale systems engineering projects, including Europa Clipper and Mars 2020 (Fosse et al., 2015a).

Leading MBSE methodologies around the time of Estefan's survey were identified as following: Harmony-SE of IBM Telelogic, IBM Rational Unified Process for Systems Engineering (RUP-SE), INCOSE Object-Oriented Systems Engineering Method (OOSEM), Vitech MBSE, Dori Object-Process Methodology (OPM), JPL State Analysis (SA) (Estefan, 2008). These tools' names have also been mentioned in numerous articles published thereafter, which suggests circulation of industry-accepted methods and tools to implement MBSE. A complete breakdown of the investigated articles has been provided in Table 5, while more popular tools within the premises of this study will be elaborated upon next.

Among the products developed in order to convey model-based design into a suitable and comprehensive form, the System Modeling Language (SysML™) was the most referenced tool. SysML, an extension of the Unified Modeling Language (UML), allows the cooperation of numerous solver applications like Matlab /Simulink, CAD/CAE design environments, and other simulation plugins that reside within the domain of system design.

The SysML™ was developed by the Object Management Group (OMG), who also actively advocated for the research and use of this language in the literature of MBSE approaches. The Object Management Group announced the adoption on July 6, 2006, and the availability of OMG SysML™ v1.0 in September 2007.

The language is referenced as "a general-purpose modeling language that is intended to support many different model-based methods, such as structured analysis methods and object-oriented methods" (INCOSE, 2017). In particular, this modeling language can be thought of as a subset of UML2 with graphical support tuned to modeling system requirements, behavior, and structure. These behavioral structures are then utilized to specify, design, verify and validate systems that may include all types of hardware, software, and organizational aspects.

The purpose-motivated characterization used in SysML diagrams includes parametric, requirement, structure, and behavior diagrams and their respective subtypes, and these aforementioned diagram types can be seen as the four pillars of SysML. The primary document for the design specifications of the OMG SysML was also published by the International Organization for Standardization (ISO) as a full international standard.

Within each SysML model, a hierarchical structure of packages exists that ultimately defines the SOI as close to real life as it can. The requirements package contains a set of requirements that would reside as system specifications for several different qualifications. The behavior package dictates how the system should act and react with auxiliary systems, while the structure package defines the internal organization of the systems' components.

In most cases, a system designer typically approaches the problem of modeling a complex system by modeling the constructs ground up through requirements packages and later detailing the SOI's behavior and activities towards many predefined operational scenarios. This approach is familiar to and generally adopted by system engineers long before modeling techniques have been developed. SysML offers a typical design language-agnostic to the system designer's methodology at the time.

The achievements of SysML-based methodologies were recognized in many of the studies reviewed in this section, although some improvements were stated to be needed. While the use of UML-based languages works in favor of cementing the relationship between software and system engineering, the benefits of the facilitation of the tool in physical systems design are found to be lagging.

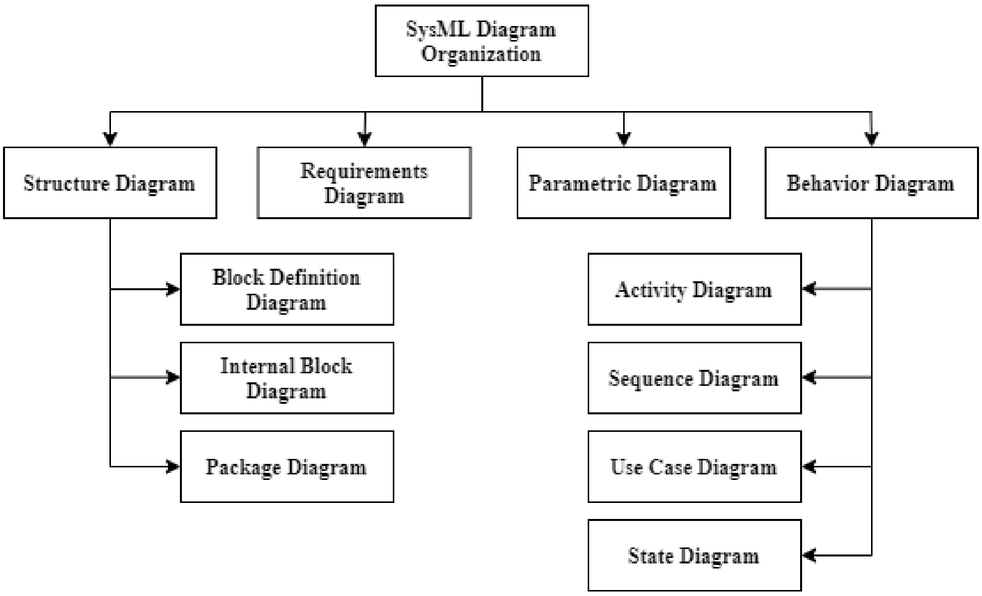

Figure 13: SysML Diagram Structure

In (Albers & Zingel, 2013), the application of the modeling language into mechanical designs was lacking in comprehensiveness, a situation that was previously inhibiting the use of such approaches in modeling function-based physical systems. To quote, “promising functional modeling approaches are emerging, although there is still a lack of adequate modeling approaches for clear specification of function-relevant physical properties of system structures preserving a maximum solution space.” The study mentions the Contact & Channel – Approach (C&C^2-A) to model technical system function-relevant physical properties.

The aim of the development of this model-based approach is to “improve the usability and comprehensibility of SysML for engineering designers and to increase the integration of physical and geometrical aspects into system models.” The approach has been applied in cooperation with the Virtual Vehicle Competence Center (Graz), AVL List GmbH (Graz), BMW AG (Munich), and the Institute of Product Development (TU Munich). These application efforts demonstrate the flexibility and modularity of the model-based approaches and their methodologies on a multidisciplinary level.

Another derivation of SysML-based design approach in mechatronic systems design is (Barbieri et al., 2014), where the authors note that “up to now SysML, as standard systems engineering language, is not widespread in the industry yet.” The paper states the following culture and general resistances towards fully adopting model-based approaches; lack of perceived value, problems with reusability, steep learning curve, and the lack of maturity of the tools.

The authors sought to relieve the resistances towards the reusability of the system models with this study by providing a design pattern framework for the high-level development of mechatronic systems while also increasing the traceability of the model changes at later stages of the design flow. This approach was only demonstrated on a workbench model, although the authors state that the next step would be to implement this framework into real industrial use cases to “show the scalability and applicability” of their approach.

Numerous examples of studies focus on alleviating problems in various aspects of the systems life-cycle activities faced by system engineers with model-based approaches. Some of these studies, like in (Nastov et al., 2017), where the authors advocate for the use of MBSto streamline verification and validation processes by combining several existing strategies to improve efficacy with respect to time, quality, and operational usage. The framework, called xviCORE, achieves these aims by describing the needs for the Domain-Specific Modeling Languages (DSMLs) that will be used for the modeling of the V&V activities. The framework is a meta-language that is composed of four languages, with dynamic, graphical, and abstract syntaxes underneath.

In (Morkevicius et al., 2017), however, SysML is detailed as neither a method nor a framework, instead of as a central artifact in a matrix-based organization. By investigating various adoption efforts fueled by SysML-powered methodologies, the authors propose a grid-formed framework, detailing requirements, behavior structures, and parametric as pillars while the problem and their respective solutions were indicated as rows, called layers of abstraction. The paper states that the “majority of MBSE methods and frameworks are conceptual and thus can hardly be used in combination with systems modeling techniques in practice.” In the end, the authors test the developed framework in a structured case study; and, while proving the applicability of the MBSE grid, falls short of supporting a full model lifecycle management of a system-of-interest.

Throughout this section of the literature review, various studies addressed challenges in different aspects of systems engineers’ design activities with the help of model-based approaches, with a large portion of these implementations being SysML-based. A deduction can be made in this regard that since SysML is both open-source and method-agnostic, it can be utilized as a versatile tool in achieving organizational aims to implement model-based approaches tailored for the domain and preexisting culture of the company.

Although it is worth mentioning that while SysML provides many conveniences to system designers, it is not without any downsides. Because of its UML inheritance, the language tool lacks the semantics for functional analysis, thus falling short of creating functional architectures without any further modifications. Another shortcoming of the language is that because of the method indifference inherent within the tool, direct implementation to the business processes without a predefined methodological framework is not possible, which furthers the arduousness of adopting MBSE in organizational settings.

The current part of the literature review can be concluded by stating that, although tools and methods for utilizing model-based approaches in commercial organizations operating in domains ranging from defense to aeronautical sectors exist for some time now, they cannot be counted as a one-shot solution to the growing need of a versatile and modular toolset. This study has also helped with identifying the lack of a fluent methodology as an essential factor to adoption with numerous examples like (Broodney et al., 2012), (Delp et al., 2013), and (Chandler & Matthews, 2013), the selection of such methodologies is thus posing as significant duress to those that are willing to adopt.

2.6. Adoption of MBSE in Industry

Among many that have contributed in some way to the topic of MBSE adoption in organizations in the literature since 2009, a series of surveys and studies were conducted in order to capture the current state of adoption in the system engineering community.

Some of these endeavors were supported by INCOSE or other institutions' efforts to illuminate the road ahead for MBSE, while other instances documented transition efforts in industrial settings. An overview of the research questions that are aimed to be answered with the following review is presented in Table 6.

Table 6: Research Questions / MBSE Adoption in Industry

No.	Research Question
Q1	What is the current state of the adoption of MBSE within industrial organizations?
Q2	What is the distribution of the organizations that are in the process of implementing MBSE into their business practices operational areas?
Q3	How does implementing MBSE into organizational settings benefit the adopters? What were the methods that they have used in order to measure the effects?
Q4	What are the challenges faced by the adopters upon commencing MBSE implementation efforts?

In order to accommodate related works published as journal papers and conference proceedings, a series of combinations of keywords were used in the previously designated databases' search engines. These combinations and their respective Boolean operators utilized for the purposes of this part of the literature review can be seen in Table 7.

Table 7: Keywords Used for Reviewing Databases / MBSE Adoption

Keyword #1	Boolean Operator #1	Keyword #2	Boolean Operator #2	Keyword #3
"MBSE"	AND	"adoption"	OR	"acceptance"

Table 7 (cont.): Keywords Used for Reviewing Databases / MBSE Adoption

“MBSE”	AND	“industry”	OR	“transition”
“MBSE”	AND	“industrial”	AND	“acceptance”
“MBSE”	AND	“industrial”	AND	“adoption”
“Model-based system engineering”	AND	“adoption”	OR	“acceptance”
“Model-driven system engineering”	AND	“adoption”	OR	“acceptance
“Model”	AND	“systems engineering”	OR	“SE”
“Model-driven”	AND	“systems”	OR	“forces”
“Model-based”	AND	“systems”	AND	“industrial”
“Model-based”	AND	“forces”	OR	“drive”
“Modeling”	AND	“industry”	OR	“industrial”
“MDE”	AND	“implementation”	OR	“application
“SysML”	AND	“adoption”	AND	“industry”

2.6.1. Classification of MBSE Adoption Literature

Within the context of this section, a total of 65 papers that have been selected from various databases published between 2008 to 2021 have been reviewed. An illustrative chart that depicts this classification can be seen in Figure 14 and Figure 15. With the addition of the papers reviewed in this section, the total number of papers and conference proceedings reviewed in the literature review section adds up to be 90.

If one were to observe Figure 14, a spark in the number of studies conducted in the field of MBSE adoption in 2012 and 2015 could be seen. A steady rise in MBSE research within organizations can also be observed in the last five years, indicating that the topic has been gaining relevance ever since its first introduction in the late ’90s. These rises in popularity might indicate that the relevance of model-based approaches increases with the way that systems engineering practitioners conduct their workflows.

As suggested by (Bonnet et al., 2015), “while the MBSE trend cannot really be questioned anymore, operationally deploying an MBSE solution on a large-scale remains a very challenging task.” Computer-aided design and graphical user interfaces have become a helpful tool in most areas of engineering design, so it would make sense that modeling systems with graphical tools and methods would also benefit the system engineers. A number of classifications were performed upon reviewing these documents, in line with what the purposes of this research required.

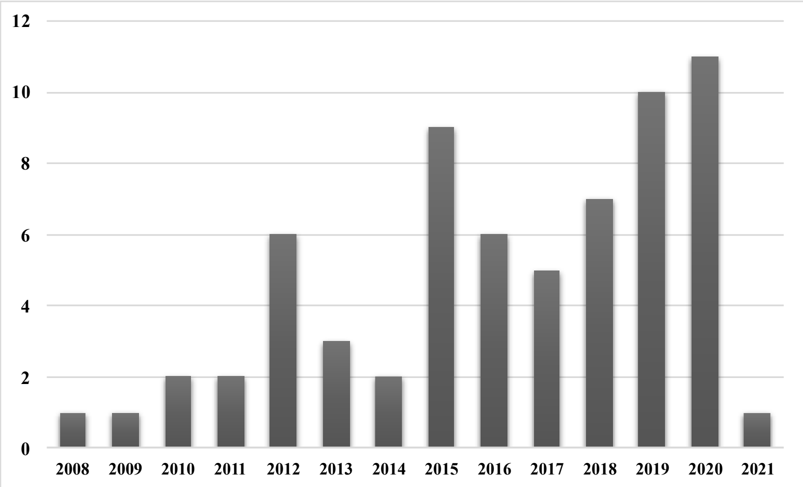

Figure 14: Reviewed Studies by Year

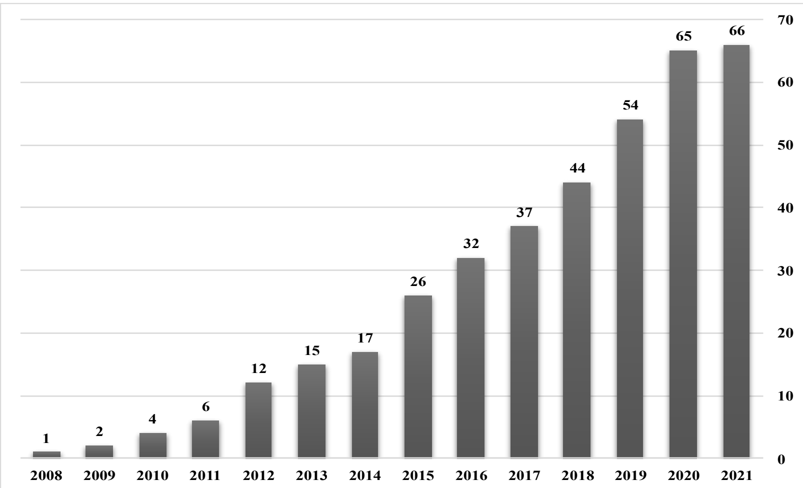

Figure 15: Accumulated Number of Studies Reviewed

As with the previous section of the review, the majority of the papers reviewed were published in a journal, while a fifth of them were parts of conference proceedings. Articles that were parts of conference proceedings were published in conferences patronized by the American Institute of Aeronautics and Astronautics (AIAA), IEEE Aerospace, Asia-Pacific Software Engineering Conference (ASPEC), and The International Academy for Production Engineering (CIRP). The majority of journal articles were published in journals like Systems Engineering, Systems and Software, Space Safety Engineering, Computer Science, and Mechatronics, along with INCOSE International, and IEEE along with others. A depiction of the distribution of the articles that were reviewed consisted of 79% of journal articles, 21% of conference proceedings.

The study was conducted among these 65 papers that have investigated various aspects of adoption of MBSE and the challenges that present themselves along with it. There are some fields of operation that these adoption efforts are taking place, with companies that operate in industrial sectors like defense, software, aerospace, and space industries along with fields like energy, education, and infrastructure.

According to (Madni & Sievers, 2018), "several aerospace companies, automotive, and defense organizations have already begun or are contemplating the transition to model-based systems engineering (MBSE)" to face an "ever-increasing complexity of systems and system development programs." An illustrative breakdown of these reviewed papers and their respective fields of operation can be seen in Table 8.

Table 8: Expected Industries Adopting MBSE: An Overview of the Literature

Operational Field	**# of References**	**References**
Defense	11	(Cole et al., 2019) (Chami & Bruel, 2018a) (Do et al., 2014a) (Bonnet et al., 2015) (Acheson et al., 2013) (Ramos et al., 2012) (Do et al., 2011) (Dent et al., 2017) (Huldt & Stenius, 2019) (Bonnet et al., 2015) (Madni & Sievers, 2018)
Nautical	1	(Arnould, 2018)
Avionics	5	(Gregory et al., 2020) (Garro & Tundis, 2012) (Brusa et al., 2016) (Malone et al., 2016) (Krupa, 2019)
Aeronautics	13	(Wibben & Furfaro, 2015) (Darpel et al., 2020) (Ferguson et al., 2020) (Bayer, 2018) (Holladay et al., 2019) (Marshall et al., 2017) (Fosse et al., 2015b) (Gao et al., 2019) (Maurandy et al., 2012) (Karban et al., 2014) (Mandutianu et al., 2009) (Kaslow et al., 2018) (Wang et al., 2016)
Automotive	3	(Pavalkis, 2016) (Kuhn et al., 2012) (Suryadevara & Tiwari, 2018)

Table 8 (cont.): Expected Industries Adopting MBSE: An Overview of the Literature

Electronics & Mechatronics	4	(Amorim et al., 2019) (Cao et al., 2011) (Tschirner et al., 2015) (Vogelsang et al., 2017)
Governmental	1	(Noguchi, 2019)
Infrastructure	3	(Hause et al., 2015) (Hernandez et al., 2016) (Poller, 2020)
Educational / Research	9	(Wu et al., 2019) (David et al., 2019) (Cameron & Adsit, 2020) (Papke et al., 2020) (Bone & Cloutier, 2010) (Cloutier et al., 2015) (Mohagheghi et al., 2013) (Selic, 2012) (White & Mesmer, 2020)
Informatics	2	(Tsadimas, 2015) (Costa et al., 2020)
Generic / Other	12	(Wilking et al., 2020) (Schöberl et al., 2020) (Montgomery, 2013) (Mohagheghi & Dehlen, 2008) (Russell, 2012) (van Noten et al., 2017) (Cloutier, 2015) (Laing et al., 2020) (Henderson & Salado, 2021a) (Soyler & Sala-Diakanda, 2010) (Inkermann, 2019) (Chami et al., 2018)

The descriptive analysis of this breakdown suggests excluding various studies regarding MBSE adoption in industry, %25 of which was conducted within the aeronautics industry, with the defense industry following it close by %21. Educational and avionics were also among top contenders, with %17 and %9 of the studies respectively. An illustration depicting this classification can be seen in Figure 16.

While the distribution of the industrial sectors that dabble in MBSE as identified with this review is shown, it is worth noting that many organizations that implement these new approaches usually also operate in areas other than the one indicated by the paper reviewed. Therefore, some form of transitivity between areas of operation may be observed within some examples.

Large corporations usually tend to extend their reach to other areas of operation in order to maximize their profits. This tendency holds true for companies that were sampled as implementing MBSE in avionics, defense, and aeronautical industries, as their workflows are usually similar and can be used interchangeably.

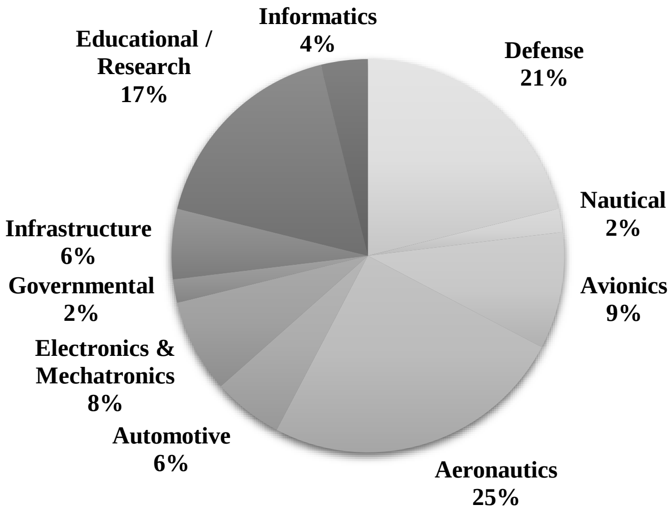

Figure 16: Distribution of Industrial Sectors Adopting MBSE

For example, Boeing is mainly known for producing commercial jetliners, but they also operate in designing and manufacturing aerospace and defense systems in line with governmental contracts. Although this distinction was not made when classifying the papers based on their functional areas of operation, it is worthwhile to note this manner of transitivity upon inspecting the results.

Including the effects of transitivity between industrial sectors in large multinational corporations, it can be observed that model-based approaches in systems engineering are primarily being implemented in organizations that accommodate defense, aeronautics, and avionics systems design. This is a trend that was validated previously by related studies and surveys (Bone & Cloutier, 2010) (Cloutier, 2015), although it is worth mentioning that the portions of said industrial sectors are decreasing as “more civil” sectors start to adopt MBSE at the face of increasingly complex systems.

Since a decent chunk of the reviewed papers was classified as working in “other” industries, it may be deemed worthwhile to look into this category that was previously regarded as generic since it was previously dismissed from the distribution mentioned previously.

Articles that were classified as generic industrial sectors in this study examine the effects of transitioning into model-based approaches in various themes that belong to specific aspects of systems design and production activities, rather than examining the effects from an industry-specific point of view.

For example, (Montgomery, 2013) investigates possible contributions of MBSE to systems integration activities, while (van Noten et al., 2017) documents the implementation of model-based approaches into discrete production lines mainly involved with designing complex mechatronic systems. (Wilking et al., 2020) researched the effects of MBSE on the value chain of organizations, while studies like (Schöberl et al., 2020) and (Mohagheghi & Dehlen, 2008) investigate the ongoing adoption process from an inter-industrial point of view.

The complete list of the papers that were deemed as "other" and their respective research areas are shown in Table 9.

Table 9: Other Industrial Adoption Papers and their Respective Research Topics

Author	**Researched MBSE Aspects**
(Wilking et al., 2020)	Value Chain
(Schöberl et al., 2020)	Drivers of Adoption
(Montgomery, 2013)	System Integration
(Mohagheghi & Dehlen, 2008)	Software Development
(Russell, 2012)	Systems Design Decision Making
(van Noten et al., 2017)	Discrete Production Lines
(Cloutier, 2015)	Intra-sectoral Adoption Trends
(Laing et al., 2020)	Model-based System Verification
(Soyler & Sala-Diakanda, 2010)	Disaster Management Systems
(Chami et al., 2018)	Development of a Toolbox for the Adoption of MBSE
(Inkermann, 2019)	Process Engineering
(Henderson & Salado, 2021b)	Value & Benefits

Studies regarding MBSE adoption have steadily grown in numbers since the formal advocacy of INCOSE in 2008 with the introduction of the MBSE Initiative. The institution later furthered this advocacy that model-based design techniques are the way forward for system designers repeatedly, as explained in the publication of Systems Engineering Vision 2025 (INCOSE, 2014). They suggest that "system models are adapted to the application domain, and include a broad spectrum of models for representing all aspects of systems." Indeed, this literature review and the papers that were investigated within its' scope revealed that MBSE practices have started to be adopted by industries that span beyond traditional defense and aerospace domains (Cloutier, 2015). This observation indicates that model-based approaches are indeed applicable in many domains with necessary alterations.

Furthering recently developed model-based approaches in a number of industrial domains imply new challenges to the stakeholders involved in designing complex systems, such as shortages of skill or lack of training. In the next section, an overview of these efforts that were most notable within the premises of this study was elaborated.

2.6.2. Adoption Efforts in Industry

This section discusses the overall approaches that previous studies have adopted in investigating the challenges that may pose themselves during transitional efforts in organizational themes regarding MBSE. An overview of these studies and an analysis of relevant data that may present itself practicable to the purposes of this study have been presented hereafter. Key findings of this research and an exposition of these results in a well-ordained way are what follows in the next section.

A series of surveys were conducted to probe the perceived value and barriers to the adoption of MBSE as issues among Robert J. Cloutier's comprehensive works. The first three surveys discuss the key findings of a Request for Information (RFI) initiated by the Object Management Group (OMG™) (Cloutier, 2015), which owns the OMG Systems Modeling Language (OMG SysML™), as a means to effectively understand the current adoption of SysML along a timeline of several years.

Later surveys were conducted with the approval of INCOSE or its UK chapter with the same aim of investigating MBSE adoption, and the latest survey in 2015 involved the participation of a broader community in preparation for the 2015 INCOSE International Workshop (Cloutier, 2015). This series of studies was well-received for the purposes of this study, mainly because they signify the trends in the engineering community over a broad range of time.

The survey design followed a threefold approach in identifying critical issues regarding MBSE adoption, along with collecting demographic information of the participants; the questions also focused on the use of MBSE in these participants' representative organizations; the survey also investigated the perceived value of the methodology. This particular instrument design stayed relatively consistent between the studies, contributing to the quality of longitudinal analysis. A specific finding within these surveys was that "there is a growing use/acceptance of MBSE in the non-DoD/Defense industries" (Wibben & Furfaro, 2015), which can be interpreted as the methodology has now reached its second phase of propagation following the early adopters in the defense industry. These early adopters are still the most significant sector that participated in the survey, followed by space systems and aircraft industries.

The results of the inquiry on the topic of adoption barriers in these industries were grouped into the following six broad categories: "perceived management issues, cost/return on investment (ROI) issues, legacy issues, broader systems engineering problems, tools & methodologies issues, and lack of skilled practitioners."

One of the more frequently referenced agencies that have appeared within the premises of this research was NASA, which has successively contributed to documenting efforts regarding their own proceedings of achieving the adoption of MBSE on an organizational level. NASA has played a consistent role in this regard, sometimes developing their own methodological frameworks with the purpose of implementing a model-based approach and applying these approaches in different organizational branches, as previously discussed in the methodologies review section.

An article that was published in Acta Astronautica in 2015 has documented the consequences of adopting an MBSE approach for the development of an operations center that will facilitate data analysis and evaluation complex for the asteroid sample return mission of the NASA OSIRIS-Rex (Holladay et al., 2019). Most aspects of designing the operational stages of a spacecraft mission can be considered as examples of complex, large-scale system design; hence the practitioners have felt the need to resort to more novel approaches like MBSE to address these complexities adequately. As the paper suggests, “MBSE has been gaining interest as a proposed solution to making the task of systems engineering more convenient, especially for large, complex projects.”

Within the context of adopting MBSE, the researchers have agreed upon facilitating the “so-called onion-model, where the system is developed in layers beginning from the top-most level” and selected Vitech’s CORE package to do so. The concept of a modular and layered approach in systems design has been frequently revisited during the SOI’s life cycle, including steps like requirements design, verification and validation, and system architecture development. The paper promotes the use of the model-based approach in these processes, stating that the final design turned out to be consistent, well-connected, and well-documented throughout its life cycle.

As part of an initiative to accelerate MBSE adoption and usage at NASA’s Johnson Space Center (JSC), (Wang et al., 2016) document the advances within the space agency related to the application of MBSE using the SysML to a number of advanced projects. The authors note that the method “has allowed engineers to control changes better, improve traceability from requirements to design and manage the numerous interactions between components.” Despite these benefits to the institution’s operations, the paper expresses the necessity to address the barriers of adoption, which were stated as the force of inertia born from the need to actuate change within large organizations, associated cost caused by the transition, and the lack of information about where to start. In order to address these barriers, JSC’s engineering team has put forth several solutions.

In order to alleviate the inertial force preventing a speedy adoption, a comprehensive training and presentation program has been initiated to convey the value behind MBSE. These campaigns were targeted towards the system integrator, in this case, the system engineers, as MBSE “provides the most benefit to the system integrator role on a project by assisting with the integration of the various disciplines.” The second challenge mentioned in the paper, namely cost issues, should be counterposed by the organization on a higher level, though, as “there is a need for a team of expert modelers that can be provided by the organization to any project.” The third barrier is mentioned to be the hardest one, and the JSC Systems Modeling Team (JSMT) has developed a comprehensive set of documents that covers the methods, guidelines, artifacts, and tools. Although the NASA SE community began evaluating the adoption of MBSE as early as 2011 (Fosse et al., 2015b), transitional examples from NASA in this review’s scope has continued from 2015 onward, from JPL’s Mars2020 (Holladay et al., 2019) to the establishment of MBSE Infusion and Modernization Initiative (MIAMI). In 2018, they were transitioning away from actually evaluating the challenges of adoption itself but rather more focused on the implementation of the practice across the workforce (Gregory et al., 2020).

During their investigation of MBSE adoption in avionic system design, Gregory et al. argue that "MBSE provides the opportunity to link various domain-specific tools together to produce a model-based framework for a system engineering project" (Bonnet et al., 2015). The investigation comprises of conducting semi-structured interviews with 25 Airbus engineers and facilitating a thematic analysis to procure recommendations to the firm's SE processes. A total of 205 responses were collected from these interviews, and these responses were then gathered around three themes revolving around the concept of MBSE adoption: process, organization, and tools. The study then goes on to propose suitable areas for further research, along with a suitable methodology to do so, as part of the Airbus' Functional Avionic Model-Oriented Usage (FAMOUS) initiative. Another high-tech organization that has attempted to incorporate MBSE in their processes was Thales Group, which is a French multinational company that designs and builds electrical systems and provides services for the aerospace, defense, security, and transportation markets. Thales has "bet on model-based systems engineering as a key lever for engineering performance improvement and has initiated an ambitious roll-out program, investing massively on both methodological and tooling aspects" (Vogelsang et al., 2017). As a result of these investments, the company has achieved a successful deployment of a model-based workbench and methodology for MBSE, namely Capella. Capella is an adaptation of a system and software architecture engineering method, Architecture Analysis & Design Integrated Approach (ARCADIA). The paper then continues on to provide a collection of best practices and pitfalls of adopting this MBSE-based approach, which will be elaborated on at a later stage.

In (Dent et al., 2017), the authors document a case study that demonstrates the application of model-based approaches to the defense procurement system of the UK Ministry of Defense (MOD), named Defense Lines of Development (DLODs). This system takes advantage of systems engineering principles as well as models upon conducting new acquisitions for the MOD. The eight-core DLODs include logistics, personnel, information, infrastructure, equipment, training, organization, and concepts & doctrine. In order to conduct these capability-based acquisitions, a number of models have been constructed as parts of an MBSE architectural framework. At a later stage of the paper, the benefits and further modification considerations have been conveyed. Benefits included the increased likelihood of program success, ease of update, reduction of interface risk, pro-active management, and increased rigor, while challenges were stated as software tool limitations, relevancy of the model to the real world, and the need for dedicated personnel.

In an attempt to capture the use of MBSE practices from the Australian and Norwegian defense perspectives, (Do et al., 2014b) document a summary of the achievements and challenges met across the contractual interface. The article gives insight about the Norwegian Frigate Acquisition project, as well as the efforts to develop model-centric acquisition processes by the Australia Defense Science and Technology Organization performed with the help of the MBSE approach taken, and why it was regarded as a success. This kind of study is regarded as necessary as it conveys a successful collaboration of the various stakeholders of the project, not just systems engineering practitioners. Agreeing on an organizational level through modeling interfaces between stakeholders has been cited as one of the problems that system integrators come up with in other papers reviewed in the literature (Hause et al., 2015). These stakeholders include an alliance of the acquisition organization, the shipbuilder, and the systems integrator communicating design pitches via models. As such, the paper states that "perhaps one of the more profound conclusions is that MBSE has been applied across the contractual boundary for around twenty years in environments where mutual trust is well developed, and mutual goals are well understood."

As for other industries that are in the wake of transitioning to model-based systems design approaches, (Vogelsang et al., 2017) offer an inside view of the ongoing efforts within the embedded systems industry. The study investigates the forces and barriers behind the adoption of MBSE in companies that are specialized in producing embedded software systems. The method that the authors have followed in order to uncover these factors is comprised of interviewing 20 experts face-to-face from 10 organizations located in Germany, then analyzing these transcripts by means of thematic coding, characterizing inertia and anxiety forces that act in terms of MBSE adoption. The aggregated quotations are then analyzed in order to be categorized in terms of a variety of aspects, identifying dependencies, fostering and hindering forces that may affect the MBSE adoption process. Fostering forces were further categorized into push and pull triggers, while hindering forces were divided into two, namely inertia and anxiety. The survey continues on to identify these aspects in terms of this organization. The authors have concluded the paper asserting that "bad experiences and frustration about MBSE adoption originate from false or too high expectations." (Vogelsang et al., 2017)

2.7. Literature Review Key Findings

Although it was beyond the scope of this literature research to delve deep into the inner workings of the methodologies used for implementing model-based approaches, some general knowledge was needed to be provided. After identifying these methodologies followed within the literature, the research then focused on the benefits and challenges of implementing these frameworks to provide a guideline for the organization that intends to transition to MBSE.

The review investigated the most prominent and referenced MBSE methodologies and toolsets available within the given timeframe and found that most of them have not been referenced much after their initial introduction. Instead, most companies and research centers have focused on developing their own methodologies, built around method-agnostic modeling language tools, such as SysML. This distinction can be seen where SysML-based original methodologies make up to be %46 of the total methodologies that were referenced between the years 2008-2021. The fact that SysML is open-source and therefore accessible for experimentation is cited to be a reason for the popularity among organizations. So far in the literature, these approaches have been implemented in various application domains such as; product line development, system requirements design, validation & verification, architectural design, and product lifecycle management, among others. This kind of flexibility provides an advantage to the organizations that seek to implement modeling throughout their specifically designed workflow environments. However, it should be noted that adapting and designing methodologies to suit specific needs take time and effort, which some companies do not have much to spare. These organizations may instead choose from several different methodologies that are predeveloped for the various needs of systems engineers, with OOSEM, OPM, Vitech MBSE, Arcadia Capella among them.

Table 10: MBSE Methodologies and Their Properties

Methodology	Properties	Modelling Language	Designer
Harmony SE	Consistent with the Vee Model and service-request-driven approach.	SysML Rhapsody TAU	IBM Telelogic
	Supports requirements analysis, system functional analysis, and design synthesis.		
	Difficulty in representing meta-models, prior work needed to modify.		
RUP-SE	Consistent with the spiral model and object-oriented concepts.	UML SysML	IBM Rational
	Inception, elaboration, construction, transition, and use case flow down activities.		
OOSEM	Consistent with the Vee model incorporating object-oriented concepts and scenario-driven approach.	SysML	INCOSE
	Supports analyzing stakeholders' needs, defining systems requirements, defining a logical architecture, validation and verification.		
	Lacks Risk & Hazard Analysis tools, shortcomings in covering the entire system life cycle.		
OPM	Object-oriented/process-oriented approach and reflective methodology.	OPD/OPL OPCAT SysML	Prof. Dori
	Requirement specifying, analysis and designing, implementing, maintaining.		
Vitech MBSE	Concurrent design, incremental approach.	SDL CORE	Vitech Corporation
	Requirements analysis, behavior analysis, architecture synthesis, and design verification and validation.		

In terms of the current state of MBSE adoption within the industry, the review has found that the pace of the transition efforts has stayed relatively the same between researches and surveys conducted throughout the timeframe.

Industrial domains related to designing large-scale systems like defense, aeronautical / space, and avionic sectors are still leading the researches involving MBSE, a trend that has been designated in studies and surveys before, like in (Cloutier, 2015), (Madni & Sievers, 2018), (Bonnet et al., 2015), (Schöberl et al., 2020), (Chami & Bruel, 2018b), and (White & Mesmer, 2020) among others. The sum of studies conducted within these aforementioned industrial domains amounts to %55 of the total studies reviewed. Through analysis of the literature, the study claims that the reason for these industries to spearhead MBSE adoption efforts is the need to streamline and simplify workflows when dealing with complex systems. The complexity of the systems-of-interest designed by systems engineering practitioners directly affects the approaches that they adopt and the willingness to adopt these approaches.

The distribution shown in Figure 16 also confirms an exciting phenomenon; aside from the popularity of MBSE in defense industry-related industries, model-based approaches adoption has been propagating to other, more “civil” engineering branches like automotive, mechatronics, infrastructure, and informatics. This kind of technology transfer between defense sectors to others has occurred in various other methods and practices before, so this transitivity only makes sense within the context.

The review has also identified a reasonable dedication to MBSE adoption in academic discussion circles. Support from a theoretical point of view is crucial for the widespread adoption of the approach, like stated in (Vogelsang et al., 2017); “MBSE complexity raises uncertainties towards effort and success of its introduction, which can be mitigated by knowledge building.” Only through adequately addressing the research need to these issues may it resolve the misunderstandings of the practitioners regarding MBSE, its tools, and processes. In this frame of reference, the benefits of MBSE adoption into system engineering processes as identified by the literature review are shown in Table 11, along with the aspects that prevent the adoption that was identified in previous studies were grouped appropriately.

Table 11: Benefits of MBSE Adoption

No.	Advantages of Adoption	Barriers of Adoption
1	Improvements in Communication and Understanding	Tools and Methodologies Issues
2	Modifiability and Modularity	Cost / Return on Investment Issues
3	Complexity Management	Perceived Value and Inertial Issues
4	Comprehensive Support of SE Life-cycle Activities	Lack of Appropriately Trained Practitioners
5	Improved Knowledge Sharing	Awareness and Maturity Issues

The constructs that were identified within the premises of this review to be the distinct advantages and barriers of adoption have been issued to be the inputs of the research in the following chapter as the design of the study is explained thoroughly. Each of these central aspects are to be subjects of measurement within the proposed model in order to correctly identify the leading causes of anxiety and inertia towards adopting MBSE practices within a major engineering organization that is established in Turkey.

2.8. Summary

In his 2012 paper (Selic, 2012) identifies the adoption of model-based engineering to be “surprisingly slow,” conveying his experience that “the tendency to ignore the greater socio-economic context in which their solutions operate is more prevalent in software development than in other technical disciplines.” Indeed, this article was one of the few reviewed that has identified socio-technical aspects as a cause of the lagging adoption of model-based approaches within the industry. Other culture-related forces that prevent the transition were given as “inadequate or flawed understanding, technology-centric mindset, and lack of system perspective.” Although being relatively old in terms of the reviewed timeframe, these factors persist in engineering communities even today. Therefore, a complete solution would be to address social, technical, and economic issues simultaneously, which was the starting point and the inspiration to write this thesis.

Throughout this chapter, a two-stage approach was undertaken in terms of identifying MBSE methodologies and tools and their applications most prominent in the industry. The advantages of model-based approaches in systems engineering and the major roadblocks in its industrial adoption have been illustrated with the help of the literature. These predetermined factors that drive and prevent MBSE adoption in the industry will be subject to trial in the following chapter as they will be the primary artifacts to measure the willingness and the resistance to adopting MBSE practices within a major private defense company in Turkey. The details of the study design will be elaborated further at the start of the next chapter.

CHAPTER 3

RESEARCH DESIGN

After subduing the task of correctly identifying the aim and the scope of the study with the help of previously conducted studies that are related to the topic at hand within the previous sections, the thesis advances to expatiate upon the primary properties and the details of the study that was conducted in order to investigate whether the claims that were hypothesized hitherto have a basis in reality. In order to achieve this, a number of qualitative analyses were made, of which the following chapter aims to delineate extensively.

The study outlined herein details a research design approach where in the first stage, forces acting on MBSE adoption that were previously identified in the previous literature review chapter were circumstantiated in full, providing substantial reasoning as to why these constructs were identified as such via quotations from previous studies.

After the arrangement of the encouraging and inhibiting constructs acting on MBSE adoption was presented, the study continues to exhibit the efforts of establishing a proposed initial model with the help of these constructs. The model presented initially will be detailed further and altered iteratively as the study collects data and performs analyses in the subsequent sections. In the latest section of this chapter, the identification and analysis of the research field are presented, along with relevant information regarding the participants of the study. Such detailing of the intended setting of the research design is assuredly compulsory, as the process of accurately determining the framework of the research design is the reason behind preparing the chapters that precede it.

3.1. Forces on MBSE Adoption

The data gathered and analyzed within the literature review section of this research have assisted in the necessary process of identification of the constructs that work towards the adoption of MBSE by practitioners. These constructs are forces that are identified to be in action; their effects are presumed to be scattered across the spectrum in terms of whether they are perceived advantageous or disadvantageous. In this subsection, the explicit details about such forces are given as the study necessitates doing so in order to lay down the foundations of the proposed model. These constructs that shall be elaborated on herein will act as a stepping stone for the actualization of the proposed theoretical model, which will then take shape according to the study's needs.

There were over 30 constructs extracted without any prior evaluation of what it may refer to, although these constructs were grouped with others through semantic analysis and the inherent meanings that they have been attributed to by their respective authors. For the purposes of defining a clear and balanced model, a total of 10 constructs were identified, with half of them having a positive connotation to adopting MBSE in workplaces, while the other half was expressing some manner of anxiety or inertia in doing so. The justification of these categorizations will also be elaborated within their respective explanations. However, the exact effect of these constructs will be determined in later stages with the aid of data accumulation from real-life settings, validation, and analysis.

For ease of viewing, these factors were identified as A1, A2, A3, A4, and A5 for facilitating (advantageous) constructs, and B1, B2, B3, B4, and B5 for the limiting (barrier) ones. These identifications were illustrated in Table 12 and Table 13 beside a traceability matrix that cross-references the constructs to the studies that examined and referenced them.

Table 12: Facilitating Constructs References

Id.	Advantages of Adoption	References	#
A1	Improvements in Communication and Understanding	(Henderson & Salado, 2021) (Huldt & Stenius, 2019) (Hale et al., 2017) (Noguchi, 2019) (Russell, 2012) (White & Mesmer, 2020) (Wilking et al., 2020)	7
A2	Modifiability and Modularity	(Chami et al., 2018) (Chami & Bruel, 2018) (Henderson & Salado, 2021) (Malone et al., 2016) (Hale et al., 2017)	5
A3	Complexity Management	(Chami & Bruel, 2018) (Chami et al., 2018) (Henderson & Salado, 2021) (Huldt & Stenius, 2019) (Russell, 2012) (Schöberl et al., 2020) (Vogelsang et al., 2017)	7
A4	Comprehensive Support of SE Life-Cycle Activities	(Noguchi, 2019) (Wilking et al., 2020)	2
A5	Improved Knowledge Sharing	(Bonnet et al., 2015) (Henderson & Salado, 2021) (Huldt & Stenius, 2019) (Hale et al., 2017)	4

Table 13: Barrier Constructs References

Id.	Barriers of Adoption	References	#
B1	Tools and Methodologies Issues	(Bonnet et al., 2015) (Chami et al., 2018) (Chami & Bruel, 2018) (Cloutier, 2015) (Malone et al., 2016) (Mohagheghi & Dehlen, 2008) (Noguchi, 2019) (Tschirner et al., 2015) (Wang et al., 2016) (Vogelsang et al., 2017)	10
B2	Cost / Return on Investment Issues	(Bonnet et al., 2015) (Cloutier, 2015) (Chami & Bruel, 2018) (Wang et al., 2016) (White & Mesmer, 2020) (Vogelsang et al., 2017)	6
B3	Perceived Value and Inertial Issues	(Chami et al., 2018) (Chami & Bruel, 2018) (Cloutier, 2015) (Huldt & Stenius, 2019) (Malone et al., 2016) (Hale et al., 2017) (Schöberl et al., 2020) (Tschirner et al., 2015) (Wang et al., 2016) (White & Mesmer, 2020) (Wilking et al., 2020)	11
B4	Lack of Appropriately Trained Practitioners	(Huldt & Stenius, 2019) (Tschirner et al., 2015) (Wang et al., 2016) (Vogelsang et al., 2017)	4
B5	Awareness and Maturity Issues	(Chami et al., 2018) (Chami & Bruel, 2018) (Huldt & Stenius, 2019) (Mohagheghi & Dehlen, 2008) (Papke et al., 2020) (White & Mesmer, 2020)	6

The preceding categorization that shows how many references each factor was attributed to has resulted in a number of conclusions. For constructs that may pose as an advantageous factor in adopting MBSE, A1 and A3 had the greatest number of references within previous studies, followed by A2, A5, and A4, respectively. As for the constructs that may act as a limiting factor to those adopting MBSE, B3 was the most referenced, followed by B1, B2, B5, and B4, with B2-B4 being tied in fourth place. Facilitating constructs received a total of 25 references, while limiting constructs received 37. Likewise, the following Figure 17 depicts the frequency distribution of the constructs in terms of their respective number of references that were elucidated as a result of this research effort.

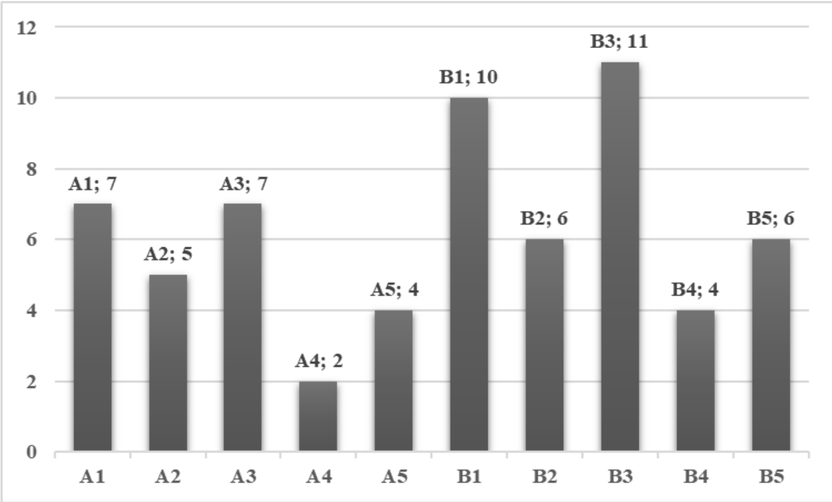

Figure 17: Frequency of the Constructs within Previous Studies

3.1.1. Advantages of MBSE Adoption

The constructs that are initially inferred as beneficial to the efforts of MBSE adoption will be discussed extensively herein. The factors that are favorable towards the adoption of model-based approaches were grouped into five main categories within the context of this study. These categories are; improvements in communication and understanding, modifiability and modularity, complexity management, comprehensive support of systems engineering life-cycle activities, and improved knowledge sharing.

<u>Improvements in Communication and Understanding (A1):</u>

Effective communication between stakeholders, designers, developers, and different engineering disciplines is one of the main tasks of competent systems engineering. (Huldt & Stenius, 2019) Furthermore, any breakdown of communication between these stakeholders at any stage of system design accumulates risk and may cause situations that were not accounted for. Since the successful implementation of the product that is to be designed requires the attention and understanding of these actors throughout the life-cycle, adopting new methods and tools when needed in order to facilitate a consensus is something to be concerned about.

Digital system models serve as the foundation for MBSE processes (Noguchi, 2019), where the system model act as the main artifact of system design and the single source of truth throughout its design phases. The system model artifact, if properly maintained to be up-to-date by the practitioners, operates as the mediator between stakeholders at each instance of system design, a common ground of understanding. Through its standardized notation, MBSE enables the communication between various domains, as well as towards non-technical stakeholders, which allows the holistic development of a system that is deemed to be satisfying multiple and even contrary stakeholder's needs. (Wilking et al., 2020) It is worth noting that implementing MBSE to the design processes alone does not consequently alleviate all miscommunication issues between partners.

There are also measures that need to be taken by the organization that contemplates adoption in order to facilitate effective communication, such as ensuring the security and the accuracy of the information available in the system model, and qualifying practitioners so that they derive similar meaning from the information that is readily made available to them. However, if these conditions are sustained by the organization, this automated integration of descriptive and analytical models enables faster execution of analytical and design work with reduced risk of miscommunication. (Noguchi, 2019)

Modifiability and Modularity (A2):

Due to its nature, systems design is an evolving and iterative task, with modifications to the initial design being made intermittently during the life cycle. These adaptations may stem from the feedback regarding changes systems' requirements from stakeholders or when a previously unexpected system behavior emerges. Whatever the reason, systems engineers are required to stay vigilant to these changes in order to maintain traceability and transparency of specific design decisions to convey information across a number of stakeholders accurately.

Using one consistent model within MBSE allows ensuring traceability throughout the development. (Wilking et al., 2020) Through increased understanding of the system in development that is facilitated from the system models, MBSE enables a greater degree of freedom in which the system designers may modify or adapt the system of interest to the emerging needs that may pose themselves along the way.

The growing environment of rapid technological change calls for a development methodology that allows and empowers the system developers and decision-makers to understand the ripple effects of changes to the capability and adapt to those changes at a much faster rate. (Hale et al., 2017)

Complexity Management (A3):

Systems are characterized by complexity (INCOSE, 2017). Thus, complexity is an inherent property that will remain the main challenge of systems design, requiring a suitable approach to view the system as a whole to understand its behavior. (Gregory et al., 2020) As the complexity of these designed systems, including systems-of-systems, evolve in time, they may exhibit emergent behavior, which is characteristically unforeseeable. These issues may disarrange the system life-cycle processes like verification, validation, and evaluation.

MBSE as an approach to handle complexity helps to decrease reluctance for developing systems that are more complex. (Wilking et al., 2020) Model-based approaches aim to produce and maintain awareness among stakeholders for the interdependencies within the system alleviates the burden of handling complexity when designing and evaluating increasingly complex systems. MBSE’s effective use of views to trace requirements, metrics, business processes, standards, and other artifacts to system design elements is a key enable supporting effective decision making within the program’s lifecycle. (Russell, 2012)

Comprehensive Support of SE Life-cycle Activities (A4):

In order for the MBSE to raise itself as a preferable approach to organizations and systems engineering practitioners, the existing toolchains and methods should encompass the entirety of the system development life-cycle. Otherwise, if several tools and methods are needed to be implemented in order to replace document-based approaches, inflicted discrepancies within the proposed framework may pose significant challenges to those who are tasked to follow it.

Any deviation from a full-scale MBSE adoption hinders the processes, actively working against its original purpose. Comprehensive support from model-based approaches would therefore decrease the additional workload needed to fulfill tasks, affecting development costs and risk aversion positively, assuring the adequate specification and a thorough verification process.

Improved Knowledge Sharing (A5):

Design decisions are often based on the overall experience of the developers, and organizations make use of their experience not only to instruct these designers to produce efficient systems but as a means to improve the overall know-how on an organizational level. They achieve this by facilitating information exchange mediums where previous experiences and design decisions are made readily available to more uninitiated employees.

As (Wilking et al., 2020) suggests, implementing adequate knowledge management to ensure the availability of experience and knowledge gained across all participants of the organization is therefore mandatory for companies no matter their size. However, simply documenting this knowledge through orthodox mechanisms may not be favorable, as these techniques suffer the same disadvantages as other document-based approaches, which were previously discussed.

As discussed within the explanation for construct A1, integrated sets of digital system models play the role of the focal point for knowledge management and technical communication. These system models are used as the principal medium of capturing knowledge and exchanging information regarding the system during its design phases, replacing a large number of discrete documents that become inconsistent across iterations. (Noguchi, 2019)

What differentiates this construct from A1 is the MBSE’s role in facilitating models as knowledge management systems, in which the information regarding the system design is rendered readily available not only to those that are stakeholders in that specific design project, but as a hub of know-how to other practitioners and designers within that organization.

3.1.2. Barriers of MBSE Adoption

The constructs that are initially inferred as having a limiting effect on the efforts of MBSE adoption are explained in this subsection. The factors that are unfavorable towards the adoption of model-based approaches were grouped into five main categories within the context of this study. These categories are; tools and methodological issues, cost and return on investment issues, inertial and perceived value issues, lack of appropriately trained practitioners, and lastly, awareness and maturity issues.

<u>Tools and Methodologies Issues (B1):</u>

As Dr. Robert Frosch, the fifth NASA administrator, stated in 1969 (Frosch, 1993), "Systems, even very large systems, are not developed by the tools of systems engineering, but only by the engineers using the tools." This remark, while emphasizing the importance of establishing the balance between various technological advancements and the people whom these improvements are intended, holds true even after more than fifty years have passed and retains one of the main pillars of socio-technical studies.

In this line of thought, the priority with adopting new tools and methodologies within organizations resides within correctly identifying the abilities and the needs of the workforce. (Holladay et al., 2019) After all, the overall value and benefits expected from new approaches would only be gained if successful implementation is assured.

Acquiring novel methodologies like MBSE and enforcing them into the workflow without prior evaluation of whether these processes comply with the needs of the current workforce could yield unexpected results. With a framework as comprehensive as MBSE, an adoption strategy that lacks forethought about these socio-technical issues may affect cost and efficiency on the contrary.

With ten quotations, construct B1 was the second most frequently mentioned force not only within its categorization but overall as well. As noted by (Bonnet et al., 2015), "whatever the benefits or the flaws, the tool is always the thing that focuses the attention of systems engineers." The issues underlined with this construct describe both a potential resistance to learning and adopting new tools and the fear that existing MBSE tools and methodologies may cause incompatibilities upon adoption.

The perception that extant tools may very well be immature is reported in many cases; for example (Chami & Bruel, 2018) notes that organizations need to pick a set of tools and train employees accordingly, yet there is no single tool that satisfies all needs. (Vogelsang et al., 2017) mentions that their research participants reported on resistance from employees regarding the immatureness of the MBSE tools, remarking "tools with bad user experience, low stability, and missing basic features are a major factor why employees resist MBSE adoption." Receiving the second most quotations may show that this construct might come as intimidating in terms of forming a barrier to successful implementation, but the truth may be different. Deficient tooling can be seen as a transient issue with this regard, considering the anxiety shall go away as soon as a sufficient tooling set is released. In a case study conducted within NASA's

Johnson Space Center, it was reported that once the tools were available to the modelers to export data, more projects were interested in adopting modeling methods and tools. (Wang et al., 2016)

Cost / Return on Investment Issues (B2):

One of the first aspects that come to mind when assessing the implementation of new processes within organizations would be the cost and the expected benefits of doing so. Companies usually have precisely tailored evaluation processes and criteria that involve the determination of an effective investment strategy, accurate cost estimation, and quantification of return on investment in order to implement new business decisions.

Since MBSE adoption requires a substantial (Chami & Bruel, 2018) upfront investment, the business decision that involves implementing MBSE would also be subject to the evaluations that were previously mentioned. Construct B2, therefore, imposes a barrier to the adoption of MBSE, possibly even before other factors come into play. The way to overcome this challenge, therefore, depends upon the management's commitment to MBSE since it is usually the administrators' decision that will enable implementation. Budget allocation is, therefore, a significant factor, but the expected return on investment affiliated with MBSE adoption is not limited to monetary funds. Schedule constraints are also effective in determining whether or not implementing new processes is worth it, and the same evaluations are also done in terms of the organization's available budget in terms of time. These constraints consolidate the existing resistance to change throughout the workforce and the management, inciting them to pursue already proven methods rather than learning an overarching system modeling technique.

Inertial and Perceived Value Issues (B3):

Up until this point, most of the challenges regarding MBSE adoption are identified to be based on both human and technological factors. Whether they come in the form of concerns that existing toolsets and methodologies are deficient, or the reasoning that a possibly hefty investment is needed on an organizational level, or the existence of change resistance on both executive and engineering levels. (Chami & Bruel, 2018)

(Hale et al., 2017) lists management support/advocacy, technical capability readiness, and organizational/cultural willingness to adopt a new methodology as the prerequisites of constructing a foundation for MBSE infusion. The following construct B3 can be seen as a culmination of these factors cultivating from these socio-technical issues as they all contribute to the inertia affecting the adoption of MBSE techniques, hence the reason why construct B3 has received the most quotations according to the review.

There are several factors that are identified within this study as affecting the overall inertia and perceived value of MBSE adoption. These factors, in some cases, reveal some similarities to other studies that have identified inertial forces behind the adoption of other comprehensive methodologies, like Agile. (Vogelsang et al., 2017) Legacy issues also play a large role here, with so much legacy data accumulated with document-based approaches, and without any clear and easy way to translate these into models, leads to the perception that the transition is, in fact, expensive and therefore not vitally needed.

However, there are factors that can be specific to MBSE in particular; for example, the incompatibility of MBSE tools with existing tools is a distinct inertia force that prevents MBSE adoption. Another example may be the fact that model-based techniques require the employment of an abstractionist state of mind, something rather new in system design processes that are facilitated within organizations. Potential mitigation of resistance to adoption stemming from organizational and cultural hurdles, therefore, should employ a holistic approach, encompassing both technological and human-related factors discussed herein. Possible solutions may include providing education, training, and access to the necessary tools, applications, and aids to keep skills fresh and transfer knowledge. (Hale et al., 2017)

Implementing solutions while faced with a rigid and uncompromising organizational structure, budget, and schedule constraints is still no easy task, though, as smaller-sized companies often lack the elbow room to provide these innovations all at once. Therefore, it is expected that larger organizations spearhead these changes by first implementing these changes to their own processes, and in time coming up with a more cost-friendly and streamlined adoption guideline, as with most technological and cultural perspectives.

<u>Lack of Appropriately Trained Practitioners (B4):</u>

Another major inhibiting factor is the availability of properly trained employees, which may come in the form of not only people who will be tasked in executing MBSE-based projects but the education level of managerial and practitioner employees positioned in different parts of the adoption curve than early adopters.

The shortcomings in training suitable employees may stem from two reasons, either the company lacks the means of providing adequate technical and sociological training because of monetary and budgetary constraints or fails to observe the value in doing so due to rigid and uncompromising organizational structure. In an effort to summarize the state-of-practice of MBSE within organizations, (Huldt & Stenius, 2019) suggested that improved skills and understanding for participants at all levels, even including external stakeholders, would prove to be the beneficiary if not vital to prevent cultural inertia.

Although it is worth noting that some of the concerns regarding the lack of training and trained experts in MBSE as a methodology coincide with other hindering constructs like ROI uncertainty and toolset compatibility issues, the reasons behind these concerns were elaborately discussed within previous barrier constructs, so going over them is regarded to be redundant. An important yet straightforward deduction about this hindering construct is that employees tend to shy away from utilizing the possible benefits of model-based approaches if they are not provided relevant training beforehand. The learning curve of MBSE-based techniques also contributes to the possible absence of training, which in turn strengthens the inertia. Thus, the training of organizations that intend to adopt MBSE should be conducted from two separate lanes entirely, the training of technical teams that will ultimately operate within the premises that MBSE will impose, and the education of the management staff that reside in the higher echelons of the organization regarding the possible value of adopting these approaches. In conclusion, other inhibitors that were explained previously could also be reduced if management, training, and structures are improved, leaving a considerable amount of work to do by the management of these organizations. Nevertheless, the process of coupling these two separate solutions would prove an arduous task for companies large and small.

Awareness and Maturity Issues (B5):

The MBSE environment consists of a highly connected network of modeling and analysis, tools, databases, and data repositories. Thus, MBSE adoption necessitates the definition, development, and deployment of a digital environment where a compatible network infrastructure, design, and modeling tools are integrated within. A transformation of such scale requires a time-phased transformation in a complex enterprise environment, where each stakeholder is expected to be somewhat aware of the capabilities and developments of a state-of-the-art model-based approach.

(Mohagheghi & Dehlen, 2008) argues that a possible integration of model-driven engineering as a set of processes within the targeted enterprise should justify itself by providing examples of somewhat explicit benefits through its compatibility of automation and overall improvements to engineering design, which would only be achieved by tools and processes that have reached a desired level of maturity. Although the aspired degree of maturity may not be the same across industries and companies, a consistent level of sophistication across the board may impact the favorability of an overall adoption strategy. Hence the inhibiting construct B5 exhibits a sociotechnical quality where the human factor once again plays a central role, with expected and perceived maturity of the processes and tools indirectly affecting the overall awareness within organizational schemes. As the scale and scope of these processes and tools increase, so too does the complexity of the socio-technical equation. These issues, if properly addressed, may override the internal resistance to change of decision-makers within companies regarding whether or not implementing MBSE would be the logical step forward. Therefore, the adoption of MBSE should not be regarded solely as an activity internal to the systems engineering organization but as a possible centerpiece of the digital engineering infrastructure as a whole.

(White & Mesmer, 2020) notes that "the philosophical wall between the land of academia and the land of practice can be extremely beneficial, with academics generating knowledge to inform and improve the state of engineering practice." Hence, there seems to be a demand for a broader approach to MBSE in the sense that the number of contributing associates, encompassing academia, regulators, authorities, and industrial experts striving towards institutionalizing initiatives whose aim would be to gather and categorize information regarding the use of model-based approaches and to convey this knowledge to whom it may concern in the form of standards, books, education programs, or training courses.

3.2. Model Construction

The development and the construction of the initial model that is being proposed forthwith represents the outcome of the analyses regarding the research conducted within the literature review. The theoretical model is constructed according to the findings of the said review in an effort to correctly identify the mechanics of existing systems engineering processes that are being conducted in the industry and potential factors that may inhibit or encourage a transition into model-based approaches.

Such an effort represents the initial phase of the research, where these constructs were highlighted in order to theorize the exact dynamics of these constructs in terms of whether they are acting in favor of or against the adoption. In other words, the rest of the study will be based upon these initial findings. The model is constituted of constructs that were hypothesized to be in a relationship with either each other indirectly or with the case for the adoption of MBSE within industries directly. The primary research model is introduced within the next subsection, along with the hypothesized relations between the constructs forming the bulk of the model and MBSE as a novel technological amelioration.

3.2.1. Initial Proposed Model

The literature review findings conducted in the previous chapter have led to the forming of a conceptual model that aims to explain the hindering and fostering forces affecting those involved in actualizing systems engineering practices. The illustration of what the basis of this conceptual model represents is presented in Figure 18.

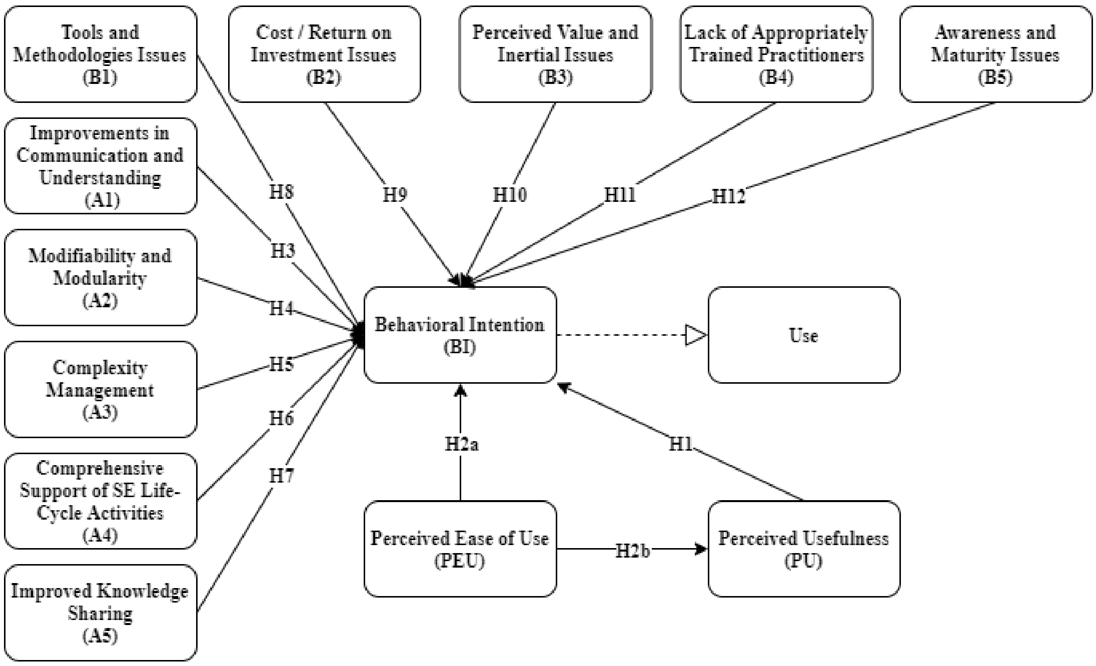

Figure 18: Initially Proposed Model for Industrial MBSE Adoption

As a result of these research efforts, the following factors affecting the outcome of a potential willingness within industries to adopt Model-Based Systems Engineering were identified; Improvements in Communication and Understanding (A1), Modifiability and Modularity (A2), Complexity Management (A3), Comprehensive Support of SE Life-Cycle Activities (A4), Improved Knowledge Sharing (A5), Tools and Methodologies Issues (B1), Cost / Return on Investment Issues (B2), Perceived Value and Inertial Issues (B3), Lack of Appropriately Trained Practitioners (B4), and Awareness and Maturity Issues (B5).

Through an evaluation of the face validity of these constructs, an effort to label them was made, with seemingly advantageous ones were labeled as A1, A2, A3, A4, and A5, and barrier constructs were labeled as B1, B2, B3, B4, and B5. These labels were initially assigned in order to provide an ease of identification merely, and thus they are but an attempt to pass a subjective judgment on the operationalization of a construct. However, the breadth of such an assessment transcends this labeling as the meaning that these constructs represent in the premise of the theoretical model was discussed extensively in the previous section. The classification of the constructs in terms of their respective relationship and the inclination to adopt MBSE is furthered with the declaration of hypotheses that aim to define the exact characteristics presented subsequently in Table 14.

Table 14: Hypotheses Regarding Constructs

Id.	Construct	Rel.	Hypothesis
PU	Perceived Usefulness	**H1**	Perceived usefulness positively affects the behavioral intention of adopting MBSE.
PEU	Perceived Ease of Use	**H2a**	Perceived ease of use positively affects the behavioral intention of adopting MBSE.
		H2b	Perceived ease of use positively affects the perceived usefulness of adopting MBSE.
A1	Improvements in Communication and Understanding	**H3**	Improvements in communication and understanding positively affect the behavioral intention of adopting MBSE.
A2	Modifiability and Modularity	**H4**	The aspect of modifiability and modularity positively affects the behavioral intention of adopting MBSE.
A3	Complexity Management	**H5**	Complexity management feature positively affects the behavioral intention of adopting MBSE.
A4	Comprehensive Support of SE Life-Cycle Activities	**H6**	Comprehensive support of SE life-cycle activities positively affects the behavioral intention of adopting MBSE.

Table 14 (cont.): Hypotheses Regarding Constructs

A5	Improved Knowledge Sharing	**H7**	The improved knowledge-sharing aspect of MBSE positively affects the behavioral intention of adopting MBSE.
B1	Tools and Methodologies Issues	**H8**	Issues regarding tools and methodologies negatively affect the behavioral intention of adopting MBSE.
B2	Cost / Return on Investment Issues	**H9**	Issues regarding the cost and the return on investment negatively affect the behavioral intention of adopting MBSE.
B3	Perceived Value and Inertial Issues	**H10**	Issues regarding the perceived value of MBSE and other anxiety issues negatively affect the behavioral intention of adopting MBSE.
B4	Lack of Appropriately Trained Practitioners	**H11**	The lack of appropriately trained practitioners negatively affects the behavioral intention of adopting MBSE.
B5	Awareness and Maturity Issues	**H12**	Issues regarding the maturity of MBSE and the awareness thereof negatively affect the behavioral intention of adopting MBSE.

With the introduction of the hypotheses in Table 14, the study formally declares the alignment of each construct on the scale of overall willingness to adopt MBSE, which was only assumed to be true previously. Although an overall subjective evaluation was deduced upon reviewing the related literature, more work is needed to validate these constructs and their respective relations and relevance to the subject at hand. In order to provide a more concrete evaluation of the reliability and the validity of the model, several actions were taken, which will be elaborated upon in the subsequent subsections.

3.2.2. Expert Review and Factor Analysis

With the number of factors acting upon the potential adoption of MBSE extracted from the literature is relatively large, the study took the effort to streamline these constructs into a more meaningful model in terms of its explanatory power. As mentioned in the detailed analysis of these factors in the previous subsection, some of the constructs may be grouped with others since they convey similar meanings and only have slight nuances in how they project the overall intention to adopt MBSE.

Since the final version of the proposed model would evidently include core constructs of the Technology Acceptance Model, some of the factors extracted from the literature would also appear to be redundant in retrospect since their effects are already being explained by Perceived Ease of Use (PEU), Perceived Usefulness (PU), and Behavioral Intention (BI). To this extent, the study had included the extra effort to consolidate the constructs to provide a final proposition of the model that has increased power of explanation over what effects MBSE transition. These efforts were driven by the detailed semantic analysis of the factors introduced in the previous subsection and how the frequency of the references within the literature was distributed.

Considering the subject's behavioral property, making an assessment with a relatively large number of factors that depict a similar meaning is counterproductive in terms of the additional benefit that they will hypothetically impose. At later phases of the analysis, highly correlated factors within the model would be detrimental to the purposes of this study, considering the model's explanatory power. To this end, ways to provide a more streamlined model were examined, taking into account the frequency of references that each construct received in the literature and the results of an expert review that was conducted as part of this study. Since the core constructs of TAM, namely Perceived Usefulness (PU), Perceived Ease of Use (PEU), and Behavioral Intention (BI), are of dire consequence to the purposes of this study, they were not included in the expert review.

The extent of the expert review encompasses the constructs extracted from the literature, which were hypothesized to be affecting the behavioral intention of adopting novel techniques in systems engineering, namely MBSE. The experts were all employed in relevant occupations, and they were asked if they agreed or disagreed with the extracted constructs in terms of whether they affect the adoption of MBSE.

The participants of the expert review were notified by e-mail, with a piece of preliminary information regarding the purposes of the study provided. Overall, eight experts participated in the review. A depiction of the results is provided in Table 15. The fully detailed dataset of the replies given by the experts was depicted in APPENDIX A.

Table 15: Results of Expert Review

Construct	Frequency in the Literature	Number of Agreed Experts
Perceived Value and Inertial Issues	11	7
Tools and Methodologies Issues	10	6
Improvements in Communication and Understanding	7	7
Complexity Management	7	6
Cost / Return on Investment Issues	6	5
Awareness and Maturity Issues	6	6
Modifiability and Modularity	5	4
Improved Knowledge Sharing	4	3
Lack of Appropriately Trained Practitioners	4	2
Comprehensive Support of SE Life-Cycle Activities	2	2

According to the results of the expert review, factors were sorted in terms of their respective mentions within the literature and the number of agreed experts on the matter. The experts who participated in this panel all have professions related to systems engineering, with their respective experience in the area ranging from 3 years to 28 years. The average experience of the participants was calculated to be 10.5 years.

With regards to the number of agreed experts in terms of the importance of the extracted constructs, the frequency in which they appear in the literature, and an assessment of the overall semantic qualities that they depict, a number of constructs were consolidated, and the proposed model was overall simplified. To this end, Improved Knowledge Sharing (A5) was merged into Improvements in Communication and Understanding (A1) due to them carrying similar overall meanings and effects. Comprehensive Support of SE Life-Cycle Activities (A4), and Lack of Appropriately Trained Practitioners (B4) was eliminated from the final proposed model due to its low-frequency score and the fact that the effect of the construct being represented in other factors.

After the evaluation process, results were reorganized, and some of the constructs were either merged into one another and therefore represented by the same construct, or they were eliminated entirely from the model. The modified version of the initial model was therefore presented in Figure 19.

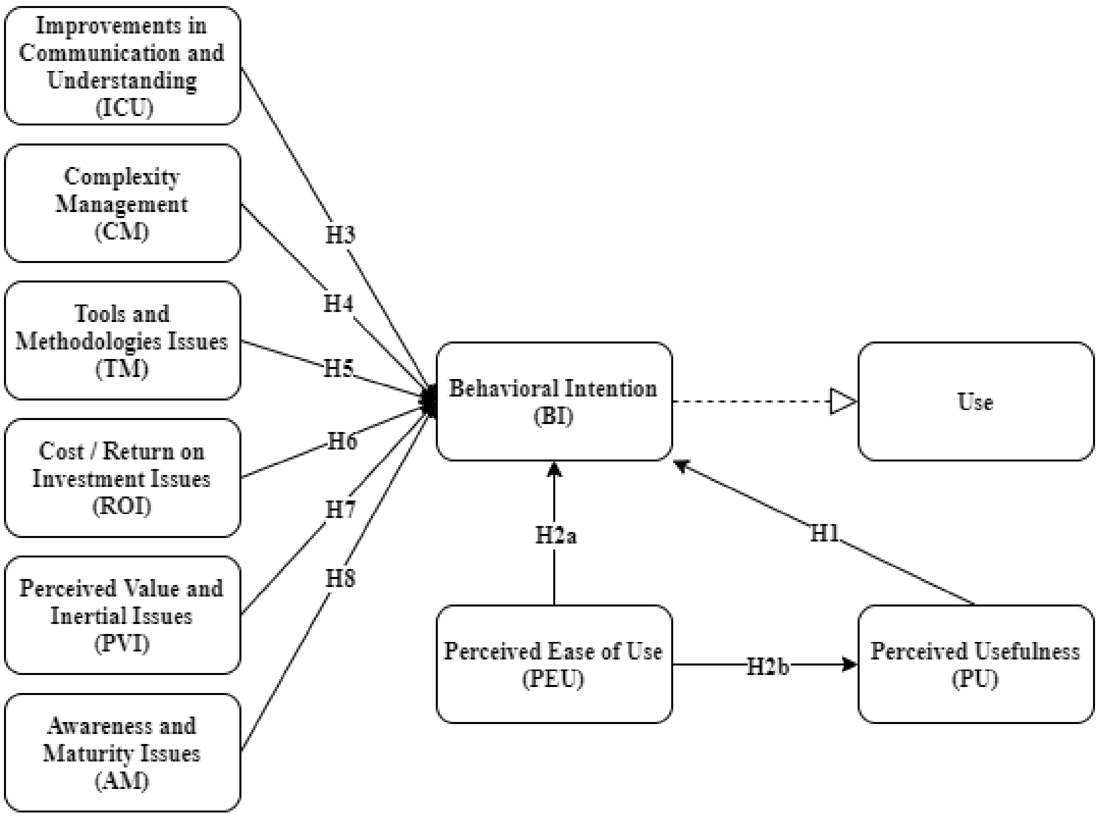

Figure 19: Modified Initial Model

In the updated version, labels of both the constructs and their respective hypotheses were also modified and reorganized for ease of viewing. Although the labels have been modified, the relation that they represent remained unchanged. The modification of labels assigned to hypotheses was depicted in Table 16.

Table 16: Modified Assignment of Construct Labels

Id.	Construct	Rel.	Hypothesis
PU	Perceived Usefulness	**H1**	Perceived usefulness positively affects the behavioral intention of adopting MBSE.
PEU	Perceived Ease of Use	**H2a**	Perceived ease of use positively affects the behavioral intention of adopting MBSE.
		H2b	Perceived ease of use positively affects the perceived usefulness of adopting MBSE.
ICU	Improvements in Communication and Understanding	**H3**	Improvements in communication and understanding positively affect the behavioral intention of adopting MBSE.
CM	Complexity Management	**H4**	Complexity management feature positively affects the behavioral intention of adopting MBSE.
TM	Tools and Methodologies Issues	**H5**	Issues regarding tools and methodologies negatively affect the behavioral intention of adopting MBSE.
ROI	Cost / Return on Investment Issues	**H6**	Issues regarding the cost and the return on investment negatively affect the behavioral intention of adopting MBSE.
PVI	Perceived Value and Inertial Issues	**H7**	Issues regarding the perceived value of MBSE and other anxiety issues negatively affect the behavioral intention of adopting MBSE.
AM	Awareness and Maturity Issues	**H8**	Issues regarding the maturity of MBSE and the awareness thereof negatively affect the behavioral intention of adopting MBSE.

3.2.3. Measurement Instrument Development

The initial evaluation of the proposed model depicting the forces that act towards or against the adoption of MBSE within the industry is done using a questionnaire. These survey items depicted below in Table 17 represent the antecedent of the efforts centered around validating the model as a reliable instrument in measuring the overall effectiveness of the proposed constructs.

In order to adequately evaluate the effects of the constructs presented herein, a measurement instrument was developed that aims to capture the view of systems engineering practitioners regarding the factors that are hypothesized to be in effect when it comes to the transition process from traditional to MBSE practices. This measurement instrument is established in the form of a questionnaire, with several items attached to each construct, all attentively prepared regarding whether they indeed gratify their respective constructs in accordance with the purposes of the study at hand. To this end, 40 items were prepared with reference to previous literature and the construct itself, as shown in Table 17.

Table 17: Questionnaire Items

QID.	Questionnaire Item	Literature
Behavioral Intention		
BI1	"The organization that I work with is likely to integrate model-based approaches in the future."	(Cloutier, 2015) (Bone & Cloutier, 2010) (Amorim et al., 2019)
BI2	"Given the opportunity, I would like to utilize MBSE for handling systems design processes."	
BI3	"The use of model-based approaches would appear to be ideal for my line of work."	
BI4	"The overall consensus within my organization favors adopting MBSE in the near future."	
BI5	"I am open to a possible integration of model-based approaches to our workflow."	
Perceived Usefulness		
PU1	"Using MBSE within system design phases would allow me to accomplish tasks more quickly."	(Davis, 1989) (Venkatesh et al., 2003) (Venkatesh & Davis, 1996)
PU2	"Model-based approaches would improve the overall performance of the engineering team."	
PU3	"Model-based approaches would increase the overall effectiveness of our work."	
PU4	"I find MBSE to be a logical next step towards improved system design processes."	
PU5	"Model-based approaches would be useful to implement and utilize."	
Perceived Ease of Use		
PEU1	"Processes regarding MBSE appear to be easy to comprehend."	(Davis, 1989) (Venkatesh et al., 2003) (Venkatesh & Davis, 1996)
PEU2	"Utilizing MBSE in my workflow appears to be relatively easy to do."	
PEU3	"I am in no need of training regarding how to use MBSE."	
PEU4	"I am confident that I would master MBSE easily."	
PEU5	"Overall, I would find MBSE easy to use."	
Improvements in Communication and Understanding		
ICU1	"Maintaining a system model artifact would play a vital role in conveying better communication across stakeholders of a project."	(Huldt & Stenius, 2019) (Henderson & Salado, 2021) (Hale et al., 2017)
ICU2	"A system model would decrease the risk of miscommunication compared to document-based approaches."	
ICU3	"Document-based approaches in systems design often fail to capture the current state of the project."	
ICU4	"Model-based approaches may help in establishing a unified understanding of system behavior."	
ICU5	"System models may pose as an effective medium for ensuring the availability of know-how within the organization."	

Table 17 (cont.): Questionnaire Items

Complexity Management		
CM1	"Traditional systems design approaches fall short of managing complex system behavior."	(Vogelsang et al., 2017) (Schöberl et al., 2020) (Huldt & Stenius, 2019)
CM2	"Existing methods and tools may be rendered ineffective in dealing with modern systems design."	
CM3	"Maintaining a system model would increase the chance to adapt to potential design changes."	
CM4	"Model-based approaches may offer a more systematic development approach in dealing with organizational complexity."	
Tools and Methodologies Issues		
TM1	"The current toolsets and methodologies of MBSE are satisfactory for performing MBSE within the organization."	(Holladay et al., 2019) (Cloutier, 2015) (Bonnet et al., 2015)
TM2	"The existing toolsets and methodologies of MBSE are compatible with the ongoing structure of our workflow."	
TM3	"The modeling languages and tools are stable and easy to understand."	
TM4	"There appears to be a consistency among what is available in terms of toolsets and methodologies that enables performing MBSE."	
Cost / Return on Investment Issues		
ROI1	"The organization has the resources, knowledge, and the ability to invest in MBSE."	(Hale et al., 2017) (Cloutier, 2015) (Vogelsang et al., 2017)
ROI2	"An investment towards adopting MBSE practices would yield increasing returns for the organization."	
ROI3	"The time and budget expenses made towards adopting MBSE would benefit the organization in the long term."	
ROI4	"The affiliated cost of adopting MBSE is justifiable for my organization."	
Perceived Value and Inertial Issues		
PV1	"Adopting MBSE would coincide with the current and long-term goals that the organization has."	(Papke et al., 2020) (Hale et al., 2017)
PV2	"Transitioning into model-based approaches would appear to be profitable for the organization."	
PV3	"There is a tendency to adopt a novel approach instead of maintaining legacy systems within the organization."	
PV4	"Transitioning from document-based processes would prove an arduous task for the organization."	
Awareness and Maturity Issues		
AM1	"Model-based approaches are mature enough to be utilized in organizational schemes."	(Chami & Bruel, 2018) (Bone & Cloutier, 2010)
AM2	"I consider myself sufficiently knowledgeable in the topic of model-based systems engineering."	
AM3	"There are clear signs that the usage of model-based approaches has benefited other companies."	
AM4	"MBSE appears to be a popular topic within systems engineering communities."	

The questionnaire items were identified with the abbreviations of the constructs designated previously, as shown in Table 17, forming a compendium of remarks that aims to capture the current state of mind of practitioners regarding MBSE.

The measurement instrument is not confined to the questionnaire regarding the constructs; however, a general overview of the properties and the overall demographics of the participants were also needed to be collected as data.

Thus, the instrument assuming a bifold structure was prepared, with the first section dedicated to gathering data of the participants themselves in terms of their relevant experience, age, gender, educational level, years within the industry, and so on. In contrast, the second part is comprised of the survey items that were presented previously. These items are hypothetically in relation to the constructs that they were identified with, with the distribution of the items arranged in a way that is correlated to the number of times it was referenced within reviewed literature.

Both parts of the survey were prepared in English originally, although, for ease of accessibility, the items were translated to Turkish in order to reach more participants.

The translation was also validated with the help of an expert by translating the questions into Turkish and then back to English once again. The complete translation of the survey that was handed to participants can be seen in APPENDIX H.

With the initial proposal of the measurement instrument presented, the study workflow necessitates that in order for the questionnaire to be instrumentalized in an academic sense, several reviews and analyses are needed to be made regarding the actual reliability and the validity of both the questionnaire and the model at hand. Only after these assessments and the resulting alterations may the instrument will assume its final form, ready to be used for this study, given that it is both reliable and valid.

The assessments conducted for the purposes mentioned earlier assumed a critical role in adequately identifying and altering the research content, with expert opinion taken into account. The following subsections detail these evaluation efforts, with both reliability and the validity of the instrument was assessed in their respective sections.

3.3. Research Field Overview

The following section adheres to a succedent manner in explaining the study field that the research was conducted in full detail, with the first and foremost subsection dedicated to introducing and explaining the actual physical and sociological properties of the research field, followed by the introduction of the participants.

A proper analysis regarding the qualities of the organization in which the research was conducted is presented in the following subsection. Identifying the exact mechanisms within the organization as a proving ground for the assumptions made within the previous parts of this study would be beneficial in terms of tailoring an adequate research instrument.

The introduction and the examination of the participants targeted by this instrument also play a vital role in coming to terms with the possible inferences that will be deduced by the study. Such a detailed explanation is undoubtedly imperative since conveying the present circumstances of the organization that acts as a host to such researches is an inseparable part of such endeavors where the affiliation of the participants to the topic at hand plays an integral part in the overall accuracy and the effectiveness of the study.

3.3.1. Study Field Analysis

The organization that acts as the subject and the testing ground for the purposes of this research is a relatively large company operating in the defense industry. The study field is situated around a Turkish defense corporation headquartered in Ankara, Turkey, with a primary operating area of research, development, and manufacture of advanced military products for air, land, and maritime forces. This portfolio of systems includes, but is not limited to, communication and information technologies, radar and electronic warfare, electro-optics, avionics, unmanned systems, land, naval and weapon systems, air defense and missile systems, command and control systems, transportation, security, traffic, automation, and medical systems.

The scope of the field research was targeted to accompany systems engineering practitioners and managerial personnel within one of these business sectors, situated in Ankara. Although the organization's current focus on MBSE was unknown prior to the research, the justification behind investigating the current status of MBSE adoption within the company was rather apparently straightforward, one of the reasons being that the previous studies conducted in the related area have shown that (Cloutier, 2015) organizations that qualify in designing and producing systems that excel in complexity management, such as defense and avionics systems were more inclined to implement and utilize novel model-based approaches. The incentive of doing so is debatable, since some of the expected or advertised benefits of MBSE are dependent upon successful or even seamless transition.

As identified within the previous sections, the reason behind the relatively large rate of participation in model-based approaches adoption efforts within the prementioned industrial sectors stems from the fact that current document-based methods have some apparent degree of frailty when it comes to designing and producing large-scale complex systems and legacy processes accommodate shortcomings as technological advances move ever forward.

3.3.2. Introduction of the Participants

The selection process of the participant pool that this study had naturally required the involvement of participants that had a distinct acquaintance with systems engineering processes. Thus, the most probable candidates were either members of the academia who were involved in researches that accommodated in some form the current trends within systems engineering in industrial scenes or the actual practitioners of those researches and movements, with the assumption that these practitioners had familiarized themselves through the precessions that are occurring in their day-to-day lives. The latter is preferred to have employment within a relatable line of work in some form to the purposes of this study.

Upon reviewing recent studies involving MBSE adoption in the previous chapter, the analysis had suggested that the most common industrial branches that had utilized in some form the practices brought forth by MBSE is the aeronautics industry, with the defense industry following it closely. Educational / Research and avionics were also among the top contenders.

The results of the literature review had necessitated the research at hand to be conducted within the industrial branches that closely coincide with areas that are most common. Luckily, as mentioned in the previous subsection, the study field accommodates such endeavors, with the company consistently maintaining and diversifying its operations within aeronautics, avionics, and defense branches, effectively corresponding to more than %50 of the most common industrial sectors found in the literature review, as illustrated in Figure 16.

Thus, the survey participants were selected according to two necessities: the participant should work in an environment where MBSE adoption is a realistic option, and that the participant should harbor some familiarities with the existing systems engineering processes. As pointed out previously, companies that have activities in the defense industry have a higher rate of adopting model-based approaches than most other industries; the first requirement can be counted as ensured. Since systems engineering as an occupation is considered to be more of a role that can be accomplished by a senior worker within the company, the latter requirement was poised to be fulfilled on its own. However, the exact composition of the participants may differ from these initial deductions, and it will be further elaborated within subsequent chapters, where the results of the survey will be laid out.

3.4. Details of Exploratory Study

The use of behavioral constructs and the quantitative nature of both the purpose and method of this study necessitated a justification of the measurement instrument in terms of its reliability. Although previous efforts documented in precursory sections have involved the use of an expert panel review and analysis of the constructs used in the model, scale items have been overlooked, with their respective qualities involving reliability and validity awaiting confirmation. Hence, before delving into the analysis of the results gathered by the study, it is required to quantify these properties appropriately. Therefore, the study has committed to the use of a pilot study to check the reliability and validity of the questionnaire items prepared in the previous chapter to measure their respective constructs.

In the following subsection, the efforts to conduct the pilot study and its possible implications regarding the potential reliability and validity of the measurement instrument were deliberated. The same quality and nature of these calculations were elaborated extensively within their respective subsections in order to provide some manner of clarity and transparency to both the pilot study and the analyses that follow.

3.4.1. Demographics of the Pilot Study Participants

Apart from directing the items specified within the questionnaire, the participants of the pilot study have also been requested some manner of detail regarding their personal information. To this end, related data regarding the age, gender, education level, and personal experience within the industry have been extracted in order to provide further information regarding the targeted demographic of this study. The distribution of these statistics was elaborated in Table 18.

Table 18: Demographics and Relative Information of Pilot Study Participants

Gender Profile		
	Frequency	**Percentage**
Female	**14**	**36,8**
Male	**24**	**63,2**
Total	**38**	**100,0**
Age		
	Frequency	**Percentage**
18-25	**14**	**36,8**
26-35	**14**	**36,8**
36-45	**6**	**15,8**
46-55	**3**	**7,9**
55+	**1**	**2,6**
Total	**38**	**100,0**
Education Level		
	Frequency	**Percentage**
Bachelor's Degree	**26**	**68,4**
Master's Degree	**9**	**23,7**
Doctorate	**3**	**7,9**
Total	**38**	**100,0**
Personal Experience within Industry		
	Frequency	**Percentage**
< 1 Years	**3**	**7,9**
1-2 Years	**11**	**28,9**
3-5 Years	**11**	**28,9**
5-10 Years	**7**	**18,4**
>10 Years	**6**	**15,8**
Total	**38**	**100,0**

The general information regarding the number of valid responses and cases is shown in Table 19.

Table 19: Case Processing Summary - Reliability Analysis

		N	%
Cases	**Valid**	38	100,0
	Excluded[a]	0	0,0
	Total	38	100,0
a. Listwise deletion based on all variables in the procedure.			

3.4.2. Reliability of the Proposed Model

After the initial fixation of the groundwork regarding the development of the proposed measurement instrument, several assessments were needed to be made in order to assure the instrument at hand yields valid and reliable results upon being conducted in real-life settings.

(Morse et al., 2002) suggests that the terms reliability and validity remain pertinent in qualitative inquiry and advocates for their maintenance. Hence, the following subsection was dedicated to detailing the efforts made to confirm the hypothetical model in terms of its reliability.

It is viewed as the most appropriate and preferred measure of reliability upon the utilization of Likert scales (Sürücü & Maslakçı, 2020). The CA coefficient is measured to have a value between 0 and 1, and the according measurement item is considered to have high internal consistency as the value gets closer to 1. No absolute rules exist for internal consistencies; however, most agree on a minimum internal consistency coefficient of .70 (Taherdoost, 2018). A classification of the various levels of internal consistency in terms of its measured Cronbach's Alpha coefficient is given in Table 20.

Table 20: Classification of Cronbach's Alpha Coefficient

Cronbach's Alpha Coefficient	**Interpretation**
> 0.9	Excellent Reliability
0.9 > α ≥ 0.7	High Reliability
0.7 > α ≥ 0.6	Moderate Reliability
0.6 > α ≥ 0.5	Low Reliability
0.5 ≥ α	Nonexistent Reliability

IBM SPSS Statistics Version 26 was utilized in order to calculate reliability statistics for the duration of this study. The Cronbach's Alpha values of each item within the questionnaire were further investigated for a potential room for improvement if any of the items connected to a construct was eliminated altogether.

If any enhancement on the reliability aspect of the measurement instrument was implied according to the CA value of each construct, the specified item was deleted in the final questionnaire. To this end, the fully detailed view of the analysis was specified in APPENDIX B, while the deleted items as a result of this effort were illustrated in Table 21. As shown in Table 21, item ICU3 was removed from construct ICU in order to provide a more suitable CA. Likewise, CM1, ROI4, and AM2 were also removed from their respective constructs.

For an exploratory or pilot study, it is suggested that reliability should be equal to or above 0.60 (Boudreau et al., 2001). However, an item that has an internal consistency value between 0.6 and 0.7 may not be sufficient for proper research. Likewise, a CA value of above 0.95 may yield mixed results, as it may suggest that some expressions found in the measuring instruments are relatively the same and do not have any distinctive features.

Table 21: Eliminated Items for Improved Reliability

Construct	Eliminated Item
Behavioral Intention	-
Perceived Usefulness	-
Perceived Ease of Use	-
Improvements in Communication And Understanding	ICU3
Complexity Management	CM1
Tools and Methodologies Issues	-
Cost / Return on Investment Issues	ROI4
Perceived Value and Inertial Issues	-
Awareness and Maturity Issues	AM2

With the assertions mentioned and threshold values in mind, the constructs defined within the measurement instrument of this study were investigated in terms of their internal consistency, with their respective Cronbach's Alpha value acting as the primary evaluation metric. The CA values of each construct are illustrated in the following Table 22. The exact calculations and elimination procedure were elaborated in APPENDIX B.

Table 22: Construct Reliability – Cronbach's Alpha

Construct	Cronbach's Alpha
Behavioral Intention	**0,780**
Perceived Usefulness	**0,743**
Perceived Ease of Use	**0,879**
Improvements in Communication And Understanding	**0,667**
Complexity Management	**0,741**
Tools and Methodologies Issues	**0,778**
Cost / Return on Investment Issues	**0,656**

Perceived Value and Inertial Issues	**0,776**
Awareness and Maturity Issues	**0,781**

As can be seen in Table 22, all constructs satisfy the necessary conditions for reliability in exploratory research, crossing the threshold of 0.6. Although values above this threshold are considered reliable, higher CA values imply better reliability, to a certain extent. Necessary elimination procedures were carried out in order to ensure better reliability, leaving all constructs well into the prementioned threshold CA value.

Table 23: Reliability Statistics of the Pilot Study

Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
0,650	0,665	36

Likewise, the overall reliability of the measurement instrument was also calculated using CA, with the purpose of ensuring the reliability of the study altogether. The associated information is shown in Table 23. It can be seen that the cumulative CA of the model also supports reliability conditions. With the initial reliability assessments achieving their purpose, the measurement instrument is verified for the actual study.

CHAPTER 4

DATA ANALYSIS AND RESULTS

This chapter is devoted to the conclusive summary of the statistical analysis of the data gathered via the measurement instrument developed with the help of preliminary analyses regarding the reliability of the model, with the help of the expert panel review and Cronbach's Alpha values calculated within the premises of pilot study which was conducted previously.

With the evaluation of the results suggested by the pilot study, the instrument was calibrated and improved upon in terms of its reliability and explanatory power. The analysis was furthered upon the realization of this new and improved version of the questionnaire, of which the utilization of its absolute breadth was reached upon gathering data for the full extent of this study.

Within the premises of this chapter, a fully detailed view of this statistical data analysis was provided, with information ranging from various properties of the data gathered during the study to exploratory and confirmatory factor analyses, up to the formation of the revised final model with the help of path analysis of the structural model.

4.1. Preface to the Analysis Results

The qualities of the data detailed herein are the result of the work carried out by this study in order to research and validate the hypotheses brought forth by the initially proposed model within the previous chapter. The efforts that are in the display within this section maintain and further the train of thought of the proposed model, developed by appropriating in the order of literature review, expert analysis, and pilot study. The study achieves this aim by putting the calibrated measurement instrument and the model to the test, with a larger data pool compared to the pilot study.

Throughout the analyses particularized within this chapter, several tools were used to help with the calculations. As mentioned in the pilot study, IBM SPSS Statistics Version 26 was used for a wide range of statistical analyses, while SmartPLS v3.3.3 was utilized for structural model analysis. Microsoft Excel included Office 2019, helped with the management of the data and provided a medium for the exchange of the database between programs.

4.2. Conclusive Summary of Data Analyses

A comprehensive overview of the analysis methods conducted with the sampled data and the respective implications and results of the analyses were discussed within this section. The results of the analyses elaborated within this subsection act as a precursor and a stepping stone to the application of the Partial Least Squares – Structural Equation Modeling (PLS-SEM) method. These analyses include ways to handle missing data within the dataset, checking for outliers and normality, reliability, and illustrating the overall demographics of the participant dataset.

4.2.1. Missing Data Handling

Since the instruments of this research include acquiring data from real persons, analysis of this data should include a way to handle any potentially missing data. Missing data in online questionnaires are common to come by, and there exist many ways to handle missing data in the context of numeral statistical research. Traditional options for missing data handling include listwise deletion, pairwise deletion, mean, regression, or hot-deck imputation methods. More modern techniques like Maximum Likelihood and Multiple Imputation are also widely used. (Dong & Peng, 2013)

With the assumption that the missing data within the dataset is missing at random, a full-case analysis, also known as listwise deletion, was applied to the dataset in order to remove any missing data, removing the cases with missing answers altogether. This approach was chosen since there are not many cases where missing data exists; hence there is no concern of losing a significant statistical power of the analyses.

Apart from disposing of the cases where a missing value is detected, three of the participants' questionnaire form was regarded as system missing because they had not filled any of the questionnaire items altogether. The case-wise elimination of missing values has yielded a total of 91 valid cases.

4.2.2. Outlier Detection

Upon dealing with the missing data, the dataset gathered from the participants has undergone statistical analysis with regard to potential outliers. Outliers are deemed as outlying observations, where the sample significantly deviates from other samples within the dataset. Potential outliers within samples may act like anomalous objects, which can render a hypothetical interpretation of the data difficult or even impossible at times. (Hodge & Austin, 2004)

For the purposes of this study, statistical approaches to detect potential outliers were evaluated as a suiting approach since the data gathered is composed of scales and hence quantifiable. A truncated mean is a calculation method of the mean value of the data, with a disregard for extreme values, namely outliers.

The significance of the difference between the truncated mean and regular mean may suggest the existence of outliers in a way that is affecting the mean value of the data significantly. To this end, a table where each item is trimmed and regular mean values are displayed in APPENDIX C.

4.2.3. Data Distribution and Normality

Statistical errors are common in scientific literature, with many of the parametric tests as statistical procedures like correlation, regression, and t-tests are conducted with the assumption of normal (Gaussian) distributed data. (Ghasemi & Zahediasl, 2012) There are many methods available to the researcher to test the normality of the data, with the most popular ones being Shapiro-Wilk, Kolmogorov-Smirnov, skewness and kurtosis, histogram, box plot, and Q-Q plot. (Mishra et al., 2019)

Apart from accounting for missing data and outliers, the dataset in this study was also examined in terms of its general distribution. To this end, the dataset has undergone normality tests, taking into account skewness and kurtosis values. Skewness and kurtosis values of each item have been illustrated in APPENDIX D, along with the descriptive statistics.

Kolmogorov-Smirnov and Shapiro-Wilk tests are also performed in order to ensure the robustness of the test results. (Mishra et al., 2019) state that the Shapiro-Wilk test is more appropriate for smaller sample sizes, while Kolmogorov-Smirnov is generally used for sample sizes larger than 50. For both of these tests, a significance value of over 0.05 is acceptable.

Both of the test results suggest that the null hypothesis that the set of data comes from a normal distribution is rejected ($p < .001$), hence the data can be said to be significantly deviating from a normal distribution. The results of these tests were disclosed in APPENDIX E.

4.2.4. Demographics

All of the data collected with the help of the measurement instrument is decoded into numeric values, including the former part of the questionnaire where some personal information of the participants was collected, including their age, gender, education, and work experience in engineering.

Table 24: Case Processing Summary

		N	%
Cases	**Valid**	91	93,8
	Excluded[a]	6	6,2
	Total	97	100,0

a. Listwise deletion based on all variables in the procedure.

The general information regarding the number of valid responses and cases was shown in Table 24, while demographic information of the participants was shown in Table 25. Overall, 97 practitioners have participated in the study, although three of the entries are regarded as system missing since the participants have only filled out the first part of the survey.

Table 25: Demographics and Relative Information of Participants

		Frequency	Percentage	Valid Percent	Cumulative Percent
Gender					
		Frequency	Percentage	Valid Percent	Cumulative Percent
Valid	Female	31	32,0	33,0	33,0
	Male	63	64,9	67,0	100,0
	Total	94	96,9	100,0	
Missing	System	3	3,1		
Total		97	100,0		
Age					
		Frequency	Percentage	Valid Percent	Cumulative Percent
Valid	18-25	23	23,7	24,5	
	26-35	34	35,1	36,2	
	36-45	20	20,6	21,3	
	46-55	12	12,4	12,8	
	55+	5	5,2	5,3	
	Total	94	96,9	100,0	
Missing	System	3	3,1		
Total		97	100,0		
Education Level					
		Frequency	Percentage	Valid Percent	Cumulative Percent
Valid	Bachelor’s Degree	54	55,7	57,4	57,4
	Master’s Degree	31	32,0	33,0	90,4
	Doctorate	9	9,3	9,6	100,0
	Total	94	96,9	100,0	
Missing	System	3	3,1		
Total		97	100,0		
Personal Experience within Industry					
		Frequency	Percentage	Valid Percent	Cumulative Percent
Valid	< 1 Years	4	4,1	4,3	4,3
	1-2 Years	22	22,7	23,4	27,7
	3-5 Years	25	25,8	26,6	54,3
	5-10 Years	21	21,6	22,3	76,6
	>10 Years	22	22,7	23,4	100,0
	Total	94	96,9	100,0	
Missing	System	3	3,1		
Total		97	100,0		

4.2.5. Reliability of the Model

Reliability, within the context of research development, is concerned with the extent "to which a measurement of a phenomenon provides stable and consistent results" (Carmines & Zeller, 1979). In this retrospect, the reliability of measurement is also closely related to its repeatability. Testing for reliability thus poses an essential step for the quality assurance of the research and its associated measurement instrument as it refers to the consistency across the parts of a measuring instrument (Taherdoost, 2018). A scale is said to have high internal consistency reliability if the items of a scale are grouped within their respective constructs and measure the alignment of the same construct. (Sürücü & Maslakçı, 2020) suggests that the reliability of the measuring instrument is an essential consideration for the study results to be healthy and lists the most frequently applied methods as test-retest reliability, alternative forms, and internal consistency tests. To this end, the most commonly used internal consistency measure that remains pertinent to the purposes of this research is to determine the internal consistency according to the Cronbach Alpha (CA) coefficient. CA values of each construct are shown in Table 26.

Table 26: Cronbach's Alpha Values

Construct	**Cronbach's Alpha**
BI	**0,908**
PU	**0,913**
PEU	**0,850**
ICU	**0,851**
CM	**0,759**
TM	**0,823**
ROI	**0,830**
PV	**0,818**
AM	**0,793**

Likewise, the overall reliability of the measurement instrument was also calculated using CA, with the purpose of ensuring the reliability of the study altogether. The associated information is shown in Table 27.

Table 27: Reliability Statistics of the Data

Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
0,739	0,763	36

4.3. Exploratory Factor Analysis

For the purpose of determining the validity of the measuring instrument, different types of validity aspects have been suggested in the literature (Sürücü & Maslakçı, 2020). Within the premises of this study, however, two main types of validity in accordance with the context and purposes of this study were investigated, namely content validity and construct validity.

As one of the most frequently used statistical methods for the purpose of evaluating content validity, factor analysis was utilized (Sürücü & Maslakçı, 2020). Factor analysis employs mathematical procedures in order to reveal patterns within the measurement instrument that describes the relations of observed variables collected within. Among factor analysis techniques, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were performed in order to clarify these patterns within the context of the study.

In order to account for the appropriateness of the data, KMO and Bartlett's Tests were performed. (Maskey et al., 2018) Results of these tests have been shown in Table 28. The acceptable KMO value is 0.5, while Bartlett's Test should have a significance level lower than 0,001. (Hair et al., 2020)

Table 28: KMO Sampling Adequacy and Bartlett's Test of Sphericity

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,700
Bartlett's Test of Sphericity	Approx. Chi-Square	1996,569
	df	630
	Sig.	,000

Factor analysis was performed in order to verify an initial extraction, utilizing principal component analysis (PCA) with varimax rotation and the Kaiser normalization method. (Taherdoost, 2018) PCA performs well when the goal is "to reduce a large number of measured variables into a small set of composite variables representing them." (Maskey et al., 2018) The resulting rotated component matrix is illustrated in Table 29.

Table 29: EFA – Rotated Component Matrix

Rotated Component Matrix[a]									
	Component								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
BI1		,716							
BI2		,809							
BI3		,758							
BI4		,826							
BI5		,776							

Table 29 (cont.): EFA – Rotated Component Matrix

PU1	,776								
PU2	,891								
PU3	,895								
PU4	,810								
PU5	,795								
PEU1			,777						
PEU2			,798						
PEU3			,792						
PEU4			,757						
PEU5			,720						
ICU1					,852				
ICU2					,758				
ICU4					,709				
ICU5					,811				
CM2						,822			
CM3						,783			
CM4						,736			
TM1				,786					
TM2				,835					
TM3				,838					
TM4				,733					
ROI1									,861
ROI2									,853
ROI3									,850
PV1								,715	
PV2								,775	
PV3								,741	
PV4								,742	
AM1							,785		
AM3							,793		
AM4							,796		

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

As can be seen in Table 29, all items that have loaded to a factor above 0.6 while also satisfying the condition of having no cross-loadings above that level were retained. The total variance explained by the factors that have been extracted with PCA accounts for 73,204% cumulative. There was a total of nine components extracted during the process, which is equal to the number of variables within the model. These results coincide with the expectation that the number of constructs within the model was accurate.

As a means to confirm the method used in EFA, another factor extraction method was reapplied to the dataset. Assuming that the factors are correlated, an oblique rotation like Promax or Direct Oblimin may be applied with the Principal Axis Factoring extraction method. (Maskey et al., 2018) The resulting structure and pattern matrices were assessed, with a total of nine factors extracted in the process, with no loading of items below 0.6 for each construct. Evaluation of a higher threshold for component loadings was left for confirmatory factor analysis.

4.4. Confirmatory Factor Analysis

Although the assurance of whether the measuring instrument is reliable poses as a vital part of research development, it is not sufficient unless combined with validity. With this train of thought, it can be said that a scale is reliable if and only if the scale also bears validity.

Content validity as a concept revolves around efforts that involve the evaluation of a measurement instrument in order to make certain that all the items related to a construct are essential for the measurement. An accurate implementation of the content validity in scale development yields an improved quality of expressions in the measuring instrument and justifies the purpose of the scale. In other words, validity explains how well the obtained data covers the actual area of investigation and how the scale items actually coincide with the researchers' initial assertions and interpretations. In order for the research to yield beneficial results in terms of scientific disciplines, the developed measuring instrument for this aim should measure what it claims. Confirmatory Factor Analysis (CFA) allows the research to validate the relationship between the observed variables and their underlying latent constructs within the context of the hypothesized model. Construct validity refers to the degree to which the measurement instrument at hand measures a concept, idea, or behavior that the developed constructs aim to depict into a functioning and operating reality. Construct validity is comprised of two components: convergent and discriminant validity.

4.4.1. Convergent Validity

The term convergent validity refers to a parameter that is used in behavioral sciences that is intended to measure the significance of the degree of relation between two measuring constructs. Thus, the use of a validated measuring instrument is said to be an assurance that the findings obtained from the analyses of the results are valid.

Items loaded above 0.5 are taken into consideration, disregarding loadings below that threshold. Items cross-loading above 0.5 shall also be eliminated. (Taherdoost, 2018) These two conditions for factor analysis, if met, also satisfy the criteria of construct validity. Item loadings were calculated using the software SmartPLS v3.3.3, which has also been the software package for the structural analysis at the later stages of this study. For the purposes of this study, a stronger threshold was dictated, requiring each item to have a loading of at least 0.6, with no cross-loading of items above 0.6. All loadings below 0.6 were hence evaluated as insignificant. The resulting outer loadings matrix is illustrated in Table 30.

Table 30: CFA – Outer Loadings Matrix

	Outer Loadings								
	AM	**BI**	**CM**	**ICU**	**PEU**	**PU**	**PV**	**ROI**	**TM**
AM1	,813								
AM3	,929								
AM4	,765								
BI1		,836							
BI2		,857							
BI3		,824							
BI4		,894							
BI5		,861							
CM2			,888						
CM3			,626						
CM4			,885						
ICU1				,901					
ICU2				,839					
ICU4				,714					
ICU5				,858					
PEU1					,867				
PEU2					,726				
PEU3					,864				
PEU4					,722				
PEU5					,677				
PU1						,812			
PU2						,908			
PU3						,891			
PU4						,805			
PU5						,885			
PV1							,767		
PV2							,877		
PV3							,837		
PV4							,729		

Table 30 (cont.): CFA – Outer Loadings Matrix

ROI1								,810	
ROI2								,949	
ROI3								,791	
TM1									**,575**
TM2									,921
TM3									,723
TM4									,681

As can be seen in Table 30, all items were loaded to their respective constructs with a value above 0.6, except TM1. The item was eliminated as a consequence, and the factor loadings were recalculated. The resulting matrices of outer loadings and cross-loadings were found satisfactory in terms of confirmatory analysis.

Construct validity evaluates how well the developed constructs explain the behavior that is attributed to each of the constructs if correctly performed. A widely accepted technique for measuring construct validity is based on the average explained variance (AVE) and Composite Reliability (CR) value deducted from each construct. (Taherdoost, 2018).

CR values should be above 0.7, while AVE should be above 0.5 for each construct in order to account for the total convergent validity of the model. (Hair et al., 2020) Results have been shown in Table 31.

Table 31: Composite Reliability and AVE Values

Construct	Cronbach's Alpha	Composite Reliability	Average Explained Variance
BI	0,908	0,907	0,661
PU	0,913	0,911	0,678
PEU	0,850	0,816	0,505
ICU	0,851	0,842	0,578
CM	0,759	0,736	0,521
TM	0,823	0,819	0,566
ROI	0,830	0,745	0,586
PV	0,818	0,822	0,546
AM	0,793	0,809	0,598

4.4.2. Discriminant Validity

Discriminant validity demonstrates the extent of discrimination between two latent variables within a dataset, in accordance with their variance in the observed variables that were associated with itself. The discriminant validity of the measuring instrument is the other significant part of construct validation. Since convergent validity is achieved as the results of the tests mentioned in the consequent subsection, checking for discriminant validity was needed.

In order to validate each construct within the instrument, the AVE values of each construct were compared to the square root of correlations between other constructs, known as the Fornell-Larcker Criterion (Benitez et al., 2020), in a diagonal form shown in Table 32. With the examination of correlations, it can be seen that the criterion for discriminant validity is reached.

Table 32: Discriminant Validity

	AM	BI	CM	ICU	PEU	PU	PV	ROI	TM
AM	**0,773**								
BI	-0,435	**0,813**							
CM	-0,193	0,416	**0,722**						
ICU	-0,300	0,412	0,177	**0,760**					
PEU	-0,258	0,366	0,143	0,242	**0,711**				
PU	-0,342	0,370	0,211	0,291	0,309	**0,823**			
PV	0,323	-0,592	-0,425	-0,285	-0,289	-0,208	**0,739**		
ROI	0,074	-0,186	-0,051	-0,101	-0,033	-0,019	-0,161	**0,811**	
TM	-0,163	0,031	-0,030	-0,110	0,051	0,095	-0,116	-0,045	**0,753**

4.5. Structural Model and Path Analysis

After achieving the results dictated by EFA and CFA, path coefficients were analyzed in order to confirm the structure of the proposed model. In order to assess the structural model that determines the causal relationships in path models, a multiple regression analysis involving PLS-SEM was utilized. PLS-SEM is often associated with the exploration and development of theory. (Hair et al., 2020)

Multiple reasons exist for PLS-SEM involvement acting in support of CFA, forming a more composite approach overall. The reasons that make structural model analysis a necessity in this research are the nature of the research area and questions, the number of constructs and observed variables within the model, and the PLS-SEM's ability to produce more accurate estimates with small sample sizes. (Hair et al., 2020)

In order to perform PLS-SEM, a check for multicollinearity of the indicators on reflective constructs, the VIF values were calculated via SmartPLS. VIF values of each construct, shown in APPENDIX F, are below 3.0; thus, multicollinearity is unlikely to be a problem.

Using SmartPLS, the PLS-SEM algorithm was run with the model and the dataset in order to calculate the path coefficients between variables and other statistics. Since PLS-SEM is a nonparametric statistical method, in order to calculate the statistical significance of the results, bootstrapping is applied with 5000 subsamples.

In general, the level of statistical significance required is ≤0.05. Nevertheless, when PLS models are tested using small sample sizes, it may be justifiable to lower the acceptable level of significance to ≤0.10. (Hair et al., 2020)

Casewise deletion has been used with a maximum of 5000 iterations as a bare minimum and no prior specification of a weighting factor. Bias-corrected and accelerated bootstrapping procedure was run with a two-tailed test setting, a significance level of 0.05. Results of the initial inner model weights and path coefficients have been shown in Figure 20.

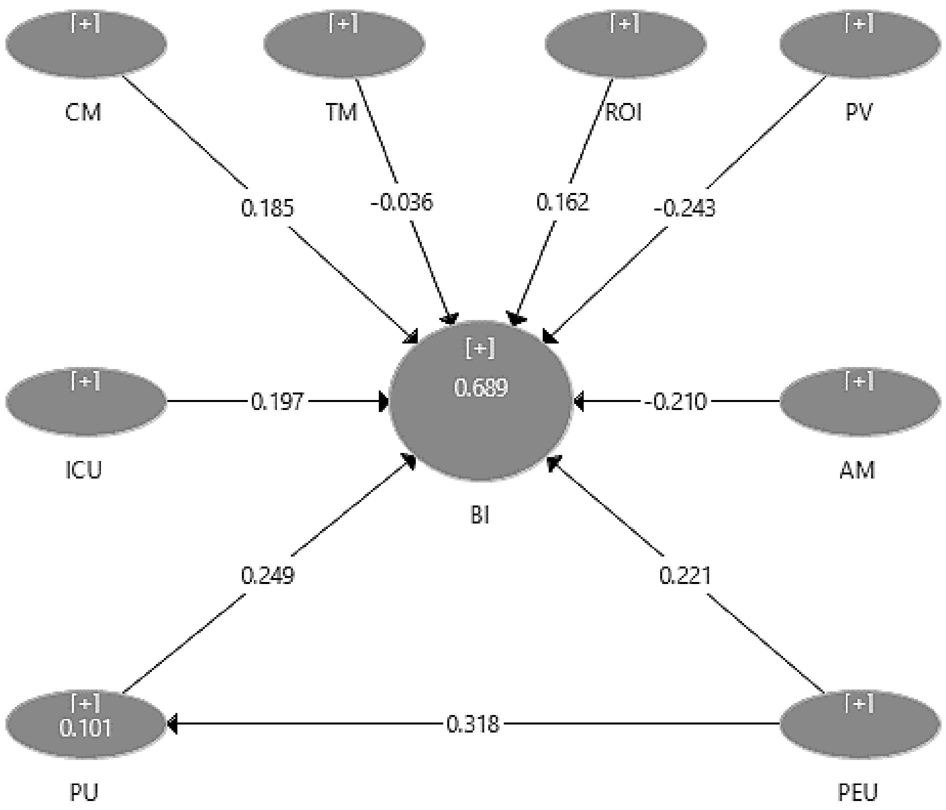

Figure 20: Path Coefficients of the Initial Model

As can be seen from Figure 20, the values of path coefficients are shown, indicating positive and negative relations. The coefficient of determination, denoted by R-squared, stands at 68,9%. The adjusted R-squared value is 65,9%. Another goodness-of-fit metric, SRMR, was found to be 0.079, which is below the recommended level of 0.08. (Hair et al., 2020)

The results of the structural model analysis with regards to the relations that were hypothesized to exist between constructs are shown in Table 33, including the results of the bootstrapping procedure, including each path coefficient, t statistic, and p-value. The verdict on these hypotheses was made with their respective p values taken into consideration.

According to the results of the bootstrap procedure, among the eight hypotheses previously declared by this study, two were rejected due to higher p-values, resulting in a rejection. Constructs TM and ROI appear not to have a significant relation with construct BI, implying that issues regarding tools and methodologies and the return-on-investment aspects of MBSE were not perceived as a relevant factor by the participants of this study.

Table 33: Structural Model Assessment – Initial Model

Relation	**Path Coefficient**	**T Statistic**	**P-Value**	**Verdict**
H1: PU→BI	0,249	2,507	0,009	**Accepted**
H2a: PEU→BI	0,318	2,297	0,022	**Accepted**
H2b: PEU→PU	0,221	2,820	0,005	**Accepted**
H3: ICU→BI	0,197	2,798	0,005	**Accepted**
H4: CM→BI	0,185	2,046	0,041	**Accepted**
H5: TM→BI	-0,036	0,635	**0,526**	**Rejected**
H6: ROI→BI	0,162	1,617	**0,106**	**Rejected**
H7: PV→BI	-0,243	2,504	0,012	**Accepted**
H8: AM→BI	-0,210	2,136	0,033	**Accepted**
R^2(BI) = 0,689, R^2(PU) = 0,101				

Although two of the hypotheses were rejected, PLS-SEM has elucidated that the model bears six significant relationships identified by constructs. Hypotheses from TAM were fully confirmed to have significant p-values for their path coefficients, and constructs devised by this study ICU, CM, PV, and AM all have significant relations with the participants' behavioral intention of using MBSE. The implications that the results of the structural model analysis hold will be elaborated further in the final chapter.

4.6. Revision of the Initially Proposed Model

To achieve the objectives of measurement model confirmation in adapting multi-item measures, a revision of the initially proposed model needed to be devised. In order to conduct this revision, an iterative process was followed, comprising primarily of adding new relations, reducing old ones, and comparing any potential improvement upon the significance of the path coefficients and the R^2 value of the overall model.

Between the design iterations made towards the initial model, the PLSc algorithm and the bootstrapping procedure with the previously specified setting was a rerun. The revision of the initially proposed model is constituted of adding and dismissing inter-factor relations, previously unexplored. Relationships that were found as significant as a result of the bootstrapping procedure were kept, while insignificant relations were disposed of as the revision progressed. The resulting final structural model and the respective path coefficients between each construct are shown in Figure 21.

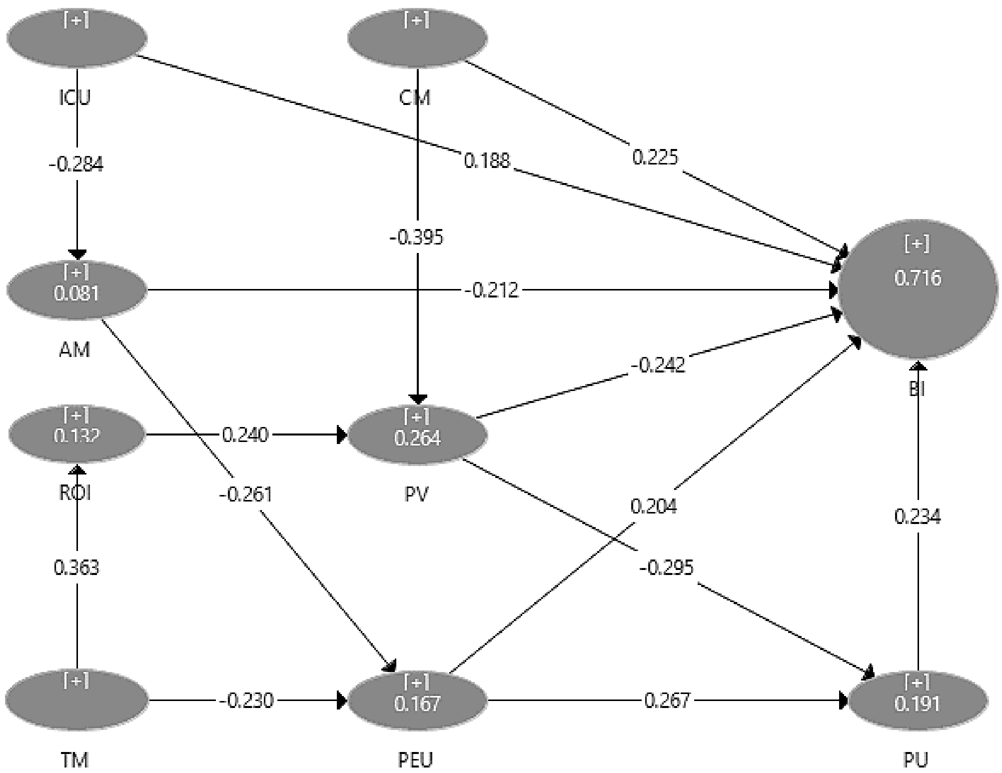

Figure 21: Path Coefficients of the Revised Model

As the iterative process involving the introduction of new relations between constructs ensued, the overall strength between relations was assessed, and the overall explanatory power of the model was evaluated. In this respect, the face validity of the relations that were added was assessed beforehand. The revision of the model with the addition of new relations is shown in Table 34.

With the addition of new relations between constructs in the final model, several of the inter-factor relationships were found significant and hence persisted in the final model. The revision has also allowed constructs ROI and TM to have a place in the model since these constructs were previously dismissed due to low significance.

Table 34: Structural Model Assessment – Revised Model

ID	Path Coefficient	T Statistic	P-Value	Verdict
H1: PU→BI	0,234	2,083	0,037	**Accepted**
H2a: PEU→BI	0,204	2,553	0,011	**Accepted**
H2b: PEU→PU	0,267	2,451	0,014	**Accepted**
H3: ICU→BI	0,188	2,225	0,026	**Accepted**
H4: CM→BI	0,225	2,088	0,037	**Accepted**
H5: TM→BI	-	-	-	**Removed**
H6: ROI→BI	-	-	-	**Removed**
H7: PV→BI	-0,242	2,679	0,007	**Accepted**
H8: AM→BI	-0,212	2,405	0,016	**Accepted**
PV→PU	-0,295	2,311	0,021	**Accepted**
AM→PEU	-0,212	2,198	0,028	**Accepted**
TM→PEU	-0,230	2,083	0,037	**Accepted**
TM→ROI	0,363	3,031	0,002	**Accepted**
ROI→PV	0,240	2,281	0,023	**Accepted**
CM→PV	-0,225	3,317	0,001	**Accepted**
ICU→AM	-0,212	2,295	0,022	**Accepted**
R^2(BI) = 0,716 R^2(PV) = 0,264 R^2(PU) = 0,191 R^2(PEU) = 0,167 R^2(ROI) = 0,132 R^2(AM) = 0,081				

The addition of new relations between latent constructs has amounted to the R-squared value of behavioral intention of the final model as 71,6%, adjusted R-squared is calculated as 69,5%. Another goodness-of-fit metric, SRMR, was found to be improved to 0.071, which conforms to good fit conditions. Although the explanatory power of behavioral intention seems to have increased slightly, the final model demonstrates more information regarding inter-factor relationships between other constructs, and more explanatory power has been explained in other endogenous constructs. The potential implications that the significance of these newly added inter-factor relations may have shall be discussed in the subsequent chapter.

CHAPTER 5

CONCLUSION

This chapter concludes the study and discusses its findings regarding the adoption of MBSE within industrial schemes in Turkey. The subsequent subsections are dedicated to asserting a conclusive remark regarding the respective results of the research topics while also identifying its possible contributions to other researchers keen on the subject. Lastly, shortcomings of the study and its' implications to future research were elaborated in order to provide a gateway to those that aim to research related topics.

5.1. Summary

Primarily, the aim of this study was to evaluate the degree of ongoing adoption of MBSE within industrial settings and to identify possible factors affecting the adoption and use of MBSE by systems engineering practitioners. The starting point of the research was to review the literature on the topic that can be considered contemporary, which enabled the identification of multiple aspects regarding MBSE and its potential adopters, namely the distribution of their respective industrial sectors, methodologies, and toolsets they prefer, elucidating the current trend in MBSE adoption.

The efforts put through in the literature review phase have helped the study with identifying the most common factors that are in effect with the overall adoption of MBSE within the industry. These forces, along with behavioral constructs extracted from TAM, were utilized as the foundation of a model that aims to explain the behavior of potential MBSE adopters. Thus, the constructs that preside over the model have been put to evaluation, with the assistance of an expert review and an exploratory study directed towards participants with the help of a measuring instrument, developed as a means to provide initial assessment during the pilot regarding reliability.

The results of path analysis, in retrospect, have shed light on possible relations identified with the help of literature review and affirmed the revision of the model. Hypotheses put forth within the premises of research methodology formation are tested with new relations added, and some of the hypotheses regarding the relation of these constructs were respectively rejected due to low statistical significance.

As the result of the structural analysis of the initial model revealed, six of the eight constructs derived and adopted from the literature into the model were found to be significantly related to the participants' behavioral intention of adopting MBSE within their workspaces. Namely, constructs PEU, PU, ICU, CM, PV, and AM are found to have a significant relationship with the construct BI in the assessment of the initial model. As a consequence, hypotheses H1, H2, H3, H4, H7, and H8 were accepted. Hypotheses H1, H2a, and H2b, which were derived from the basis of the final version of TAM, were verified within this model.

The path coefficients of the accepted hypotheses of the initial model were also assessed according to their direction of correlation. In this respect, hypotheses H1, H2, H3, H4, H7, and H8 denoting relations within the model were evaluated and verified. As can be seen from Table 33, relations between PV and AM had negative path coefficients with significant p-values. All other accepted relations were positive, thus assuring the direction of these relations as stated by their respective hypotheses.

Hypotheses H5 and H6 that binds constructs ROI and TM to BI, respectively, have been rejected due to the low significance of the relation. For the participants of this study, issues regarding return on investment and tools and methodologies were not significant factors in choosing MBSE as a way forward. This result has its implications in a way that was not foreseen by this study initially, especially since the literature review has a section dedicated to the tools and methodologies that are in use in places where MBSE has successfully been implemented.

The associated cost of adopting MBSE within the company, in other terms, ROI, has not been perceived as a significant factor by the participants, who are mostly engineering practitioners and not managerial staff. Hence, it can be reasonable that the designers do not perceive ROI and TM as necessarily important since these concerns are more predominantly voiced by financial teams and managerial echelons within the company. Although ROI and TM appear to not relate to BI directly, they may have indirect effects through other constructs, and the revision of the initial model explored these possibilities.

As the revision progressed, inter-factor relationships in the initial model have been investigated by adding a relation between two constructs and analyzing PLSc results. Instead of two hypotheses that were rejected in the initial model, the final model comprises seven new relations, which were found as having significantly low p-values.

In the final model presented by this study, perceived value and inertial issues have been found as affecting perceived usefulness negatively. The relation is significant; hence it can be said that the participants who have formed inertial anxiety about adopting MBSE have trouble perceiving the methodology as useful. The result concurs with the findings gathered from the literature. The reason for this result may stem from the possibility that there are investment decisions towards maintaining legacy systems in place. Human nature necessitates that novel paradigms are met with some level of resistance or with limited acquiescence. Thus the human factor plays a central role, especially if the decision-making personnel within the organization have different levels of MBSE knowledge and adequate time for training is not granted. (Chami & Bruel, 2018)

Awareness and maturity issues have been found to affect perceived ease of use negatively. A comprehensive adoption effort of MBSE can have a consequential impact on both the systems engineering teams and other engineering specialty departments on an organizational level. Mitigating the issues caused by the possible awareness and maturity of MBSE, or the lack thereof, is a duty that falls to stakeholders much larger than the organizations that intend to adopt it by themselves.

Issues regarding the existing tools and methodologies that are in offer for MBSE implementation were found to be significantly affecting both the perceived ease of use and concerns about return on investment of MBSE. The literature review has asserted that these issues may be overcome once the related tools are made available to the practitioners. However, at its current state, the perception that existing MBSE toolsets are deficient understandably casts a shadow on the pretense that model-based approaches introduce streamlined and efficient systems engineering practices.

Participants' doubts regarding return on investment issues negatively affect perceived value, which in turn lowers the behavioral intention of adopting MBSE. If the management team is not convinced that model-based approaches will provide any significant benefits to their business processes, the cost affiliated would likely deter them from proceeding with making necessary investments. As suggested before, good tools are too costly (IBM Rational, Mathworks) (Cloutier et al., 2015), and more often than not, the intended budget of engineering projects is strict, thus keeping novel modeling approaches at low priority compared to the costs of actualizing the project at hand.

The complexity management aspect of model-based approaches in system design was found to be significantly affecting the perceived value negatively. Thus, it can be said that participants are particularly tempted to explore possibilities where it helps them with designing systems in spite of complexity. The inherent complexity is not necessarily limited to the system itself; as (Schöberl et al., 2020) suggest, besides product-related complexity, there is also organizational complexity, which requires a more systematic development approach, thus making it in need to be accounted for. These issues that reside within the task of producing successful complex systems may render existing methods and tools ineffective (Chami & Bruel, 2018), and they may pose as the reason why the model-based approaches were originated in the first place, and why complexity management is cited as one of the main drivers of MBSE adoption in organizations.

Another positive factor, the possibility of maintaining an increased amount of communication across teams and project stakeholders with the utilization of model-based approaches like MBSE, persists over fears of awareness and maturity of the methodology. With these assertions put forth by the final model, it can be said that the factors that were hypothesized to be a positive aspect in the minds of practitioners were indeed helping them overcome possible inertial anxiety of adopting MBSE.

As with most socio-technical challenges, relevant resistance to change is alleviated after a considerable time has passed, and the improvements in quality and cost reduction help novel approaches to become somewhat mainstream. For this reason, pertinent employees and managerial personnel should be exposed to pieces of evidence that successful projects that have benefited from MBSE sooner rather than later. (Bone & Cloutier, 2010)

For the reasons mentioned above, MBSE adoption efforts require an organizational-level proactive approach that there is substantial value to be gained upon implementation. Since MBSE provides the most benefit to those working as the system integrator, the assertion that it provides a considerable amount of return on investment may have to be championed by them.

5.2. Contributions of the Study

Despite being presented as an opportunity to improve upon existing systems engineering processes at a time where engineered systems are evolving into large-scale system-of-systems, efforts regarding the industrial adoption of MBSE have progressed only to some extent. As described in the previous portions of this study, there were specific reasons for this hiatus. MBSE should, without a doubt, prove its efficiency and maturity before companies commit to a comprehensive redefinition of their business practices; since time and cost efficiency is vital for commercial projects. The INCOSE Systems Engineering Vision 2025 (INCOSE, 2014) describes the current state of MBSE as "grown in popularity as a way to deal with the limitations of document-based approaches, but is still in an early stage of maturity similar to the early days of CAD/CAE."

MBSE, as documented in previous literature that was reviewed in this study, has put forth advancements in many facilities that intend to advance, streamline and automate systems design processes that were traditionally absent from document-based approaches. The benefits of these novel model-based approaches in systems design appear to be numerous, but the resources and effort needed to transition into these approaches remain as a hindrance to organizations that intend to adopt.

The study provides a substantial amount of discussion on the fostering and hindering forces acting upon MBSE adoption in organizations, collected from findings of previous literature and tested in real-life settings. The exact nature of the relations between these forces, the degree that they affect MBSE adoption has been the primary research question of this study, and the analysis of the model designed to achieve this very aim shall act as a substantial resource for organizational and academic actors interested in the matter. To this end, findings of other companies that have confronted these issues previously have been documented and reviewed, and the MBSE adoption framework that has been put to evaluation within the premises of this study may assist other companies and institutions alike.

The research bears the significance of being one of the few cases where the adoption of a novel approach is studied within a company in Turkey. During the literature review, it has been revealed that a considerable portion of studies regarding MBSE adoption in related literature is situated in sectors related to the avionics and defense industry, with organizations like BAE Systems, NASA, Thales UK, and Boeing spearheading the efforts. This study hence contributes to these researches made towards elucidating the current state of MBSE adoption within defense companies, as the first example of such a study to be conducted within a defense company operating in Turkey.

5.3. Shortcomings and Future Implications

Within the last section of the study, possible shortcomings of the study and its future implications that have occurred within the timeframe of the conduction of research have been elaborated and discussed within their respective subsections.

5.3.1. *Shortcomings of the Research*

One of the major inhibitors of the explanatory power of the analysis conducted regarding the evaluation of the model stems from the inherent properties of the sample space. Although the study has reached a sufficient sample size in terms of the number of constructs being explained within the model, it is just above the recommended level of ten per estimated parameter (Schreiber et al., 2006).

The field of study also bears a significant effect in this afterthought since the engineering practitioners who participated in this study are all employed within one organization situated in Turkey that specializes in the design, production, and assembly of defense technology-related goods. Although the results of the literature review have put forth the significance of the portion of MBSE adopters in the defense industry when compared to other industrial sectors, the exact distribution between industrial sectors that may employ MBSE practices in the future is not adequately reflected by this study.

Some of the shortcomings that have not been accounted for within the premises of this study come from the selected method of structural model assessment to validate the model. Although the strength of path analysis stems from its ability to decompose relations among constructs and to test the credibility of a theoretical model, actual utilization of such a statistical technique is implies the existence of a set of assumptions, which are highly restrictive in nature. (Schreiber et al., 2006) To this end, the validation of the structural model assumes that the causal model was measured without error, and if any error exists, they are assumed to be not intercorrelated. These assumptions are highly desirable but may not be reproducible in real-life settings.

Almost all of the variables of interest in the proposed model of MBSE adoption were not directly observable. Variables such as perceived ease of use, perceived usefulness, awareness and maturity, perceived value, and inertial issues are latent constructs. The use of a single indicator to fully capture the complexities of such a construct as required in path analysis is impractical.

Completely encapsulating the nature of those variables in path analysis requires that one use multiple indicators for each latent construct. On the other hand, there are reservations that are related to the factor extraction method. Principal components analysis is a method that is focused on explaining as much of the total variance as possible and thus extracts factors that contain primarily common variance. The shared variance between extracted factors is regarded as applicable, but if any error exists, its variance is also extracted. Methodologists advocating PCA note that the amount of error variance included when starting with total variance is most often negligible (Hair et al., 2020) because the process of extracting factors removes most if not all of the error variance.

5.3.2. *Future Implications of the Research*

Shortcomings of the study that were elucidated in the preceding subsection also provide a healthy basis for its potential implications for future research. With this train of thought, identification of these shortcomings may imply both theoretical and practical topics for future research.

The properties of the field of research that was conducted within the premises of this study, although being qualified for the analysis that was carried out afterward, were ultimately restricted to small sample size. The restrictions do not end with the number of participants, however, as the study was also conducted with engineering practitioners participating within a single company in Turkey. If more companies in the process of adopting MBSE were identified, the study could be expanded to a multitude of companies to strengthen the explanatory power of the measurement instrument and the final model, naturally expanding the sample size in the process. The resulting framework would perhaps benefit companies who seek to go through similar processes regarding the adoption of MBSE.

The study also need not be constricted within the confines of the defense sector; as the literature has suggested, MBSE as an approach has become relevant in other industrial sectors as the adoption ensued. (Cloutier, 2015) Accurate distribution of sectors, as elucidated by this study, maybe the subjects of future research concerning MBSE, providing a more conclusive answer to the industries' current needs.

Another implication that this study may bear for researches with similar nature in the future would be to devise a possible improvement upon the number of constructs and the refinement thereof. Two of the constructs in the initial model were left as invalid upon the conduction of structural model analysis. Only through inter-factor relations was the model improved. Future work may include a further elaboration of these constructs and the meanings that they hold.

REFERENCES

Acheson, P., Dagli, C., & Kilicay-Ergin, N. (2013). Model based systems engineering for system of systems using agent-based modeling. *Procedia Computer Science*, *16*, 11–19. https://doi.org/10.1016/j.procs.2013.01.002

Albers, A., & Zingel, C. (2013). Extending SysML for engineering designers by integration of the contact & channel - Approach (C&C2-A) for function-based modeling of technical systems. *Procedia Computer Science*, *16*, 353–362. https://doi.org/10.1016/j.procs.2013.01.037

Amorim, T., Vogelsang, A., Pudlitz, F., Gersing, P., & Philipps, J. (2019). Strategies and Best Practices for Model-Based Systems Engineering Adoption in Embedded Systems Industry. *Proceedings - 2019 IEEE/ACM 41st International Conference on Software Engineering: Software Engineering in Practice, ICSE-SEIP 2019*, 203–212. https://doi.org/10.1109/ICSE-SEIP.2019.00030

Arcaini, P., Mirandola, R., Riccobene, E., & Scandurra, P. (2020). MSL: A pattern language for engineering self-adaptive systems. *Journal of Systems and Software*, *164*, 110558. https://doi.org/10.1016/j.jss.2020.110558

Arnould, V. (2018). Using model-driven approach for engineering the system engineering system. *2018 13th System of Systems Engineering Conference, SoSE 2018*, *June*, 608–614. https://doi.org/10.1109/SYSOSE.2018.8428769

Ashby, W. R. (1956). *An Introduction to Cybernetics*. J. Wiley and Sons. https://doi.org/10.5962/bhl.title.5851

Barbieri, G., Kernschmidt, K., Fantuzzi, C., & Vogel-Heuser, B. (2014). A SysML based design pattern for the high-level development of mechatronic systems to enhance re-usability. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *19*(3), 3431–3437. https://doi.org/10.3182/20140824-6-za-1003.00615

Bastedo, M. (2004). Open Systems Theory. *The SAGE Encyclopedia of Educational Leadership and Administration*, 1–2.

Bayer, T. (2018). Is MBSE helping? Measuring value on Europa Clipper. *IEEE Aerospace Conference Proceedings*, *2018-March*(May 2009), 1–13. https://doi.org/10.1109/AERO.2018.8396379

Beer, S. (1959). *Cybernetics and management.* English Universities Press.

Beery, P. (2016). *A Model Based Systems Engineering Methodology for Employing Architecture in System Analysis: Developing Simulation Models Using Systems Modeling Language Products to Link Architecture and Analysis*. http://calhoun.nps.edu/handle/10945/49363

Bertalanffy, L. Von. (1950). An outline of general system theory. *British Journal for the Philosophy of Science*, *1*(2), 134–165. https://doi.org/10.1093/bjps/I.2.134

Bhunia, A. K., Sahoo, L., Shaikh, A. A., Churchman, C. W., Ackoff, R. L., Arnoff, E. L., Bhunia, A. K., Sahoo, L., & Shaikh, A. A. (1950). Introduction to Operations Research. In *Springer Optimization and Its Applications* (Vol. 153). Wiley. https://doi.org/10.1007/978-981-32-9967-2_1

Bijlsma, T., Suermondt, W. T., & Doornbos, R. (2019). A knowledge domain structure to enable system wide reasoning and decision making. *Procedia Computer Science*, *153*, 285–293. https://doi.org/10.1016/j.procs.2019.05.081

BKCASE Editorial Board. (2016). Guide to the Systems Engineering Body of Knowledge. *Guide to the Systems Engineering Body of Knowledge (SEBoK), October 2020*, 945. http://g2sebok.incose.org/app/mss/menu/index.cfm

Bleakley, G., Lapping, A., & Whitfield, A. (2011). Determining the right solution using SysML and model based systems engineering (MBSE) for trade studies. *21st Annual International Symposium of the International Council on Systems Engineering, INCOSE 2011*, *1*, 778–790. https://doi.org/10.1002/j.2334-5837.2011.tb01243.x

Bone, M., & Cloutier, R. (2010). The Current State of Model Based Systems Engineering : Results from the OMG ™ SysML Request for Information 2009. *8th Conference on Systems Engineering Research - CSER*, 225–232.

Bonnet, S., Voirin, J.-L., Normand, V., & Exertier, D. (2015). Implementing the MBSE Cultural Change: Organization, Coaching and Lessons Learned. *INCOSE International Symposium*, *25*(1), 508–523. https://doi.org/10.1002/j.2334-5837.2015.00078.x

Bougain, S., & Gerhard, D. (2017). Integrating Environmental Impacts with SysML in MBSE Methods. *Procedia CIRP*, *61*, 715–720. https://doi.org/10.1016/j.procir.2016.11.196

Boulding, K. E. (1956). General Systems Theory—The Skeleton of Science. *Management Science*, *2*(3), 197–208. https://doi.org/10.1287/mnsc.2.3.197

Bozzano, M., Cimatti, A., Katoen, J. P., Katsaros, P., Mokos, K., Nguyen, V. Y., Noll, T., Postma, B., & Roveri, M. (2014). Spacecraft early design validation using formal methods. *Reliability Engineering and System Safety*, *132*, 20–35. https://doi.org/10.1016/j.ress.2014.07.003

Böhm, W., Junker, M., Vogelsang, A., Teufl, S., Pinger, R., & Rahn, K. (2014). A formal systems engineering approach in practice: An experience report. *1st International Workshop on Software Engineering Research and Industrial Practices, SER and IPs 2014 - Proceedings*, 34–41. https://doi.org/10.1145/2593850.25938566

Britto, R., Smite, D., Damm, L. O., & Börstler, J. (2020). Evaluating and strategizing the onboarding of software developers in large-scale globally distributed projects. *Journal of Systems and Software*, *169*, 110699. https://doi.org/10.1016/j.jss.2020.110699

Broodney, H., Dotan, D., Greenberg, L., & Masin, M. (2012). Generic approach for systems design optimization in MBSE. *22nd Annual International Symposium of the International Council on Systems Engineering, INCOSE 2012 and the 8th Biennial European Systems Engineering Conference 2012, EuSEC 2012*, *1*, 185–201. https://doi.org/10.1002/j.2334-5837.2012.tb01330.x

Brusa, E., Ferretto, D., Stigliani, C., & Pessa, C. (2016). A model based approach to design for reliability and safety of critical aeronautic systems. *CEUR Workshop Proceedings*, *1728*, 56–64.

Cameron, B., & Adsit, D. M. (2020). Model-Based Systems Engineering Uptake in Engineering Practice. *IEEE Transactions on Engineering Management*, *67*(1), 152–162. https://doi.org/10.1109/TEM.2018.2863041

Cao, Y., Liu, Y., & Paredis, C. J. J. (2011). System-level model integration of design and simulation for mechatronic systems based on SysML. *Mechatronics*, *21*(6), 1063–1075. https://doi.org/10.1016/j.mechatronics.2011.05.003

Carmines, E., & Zeller, R. (1979). Reliability and Validity Assessment. In *Reliability and Validity Assessment*. SAGE Publications, Inc. https://doi.org/10.4135/9781412985642

Chami, M., Aleksandraviciene, A., Morkevicius, A., & Bruel, J.-M. (2018). Towards Solving MBSE Adoption Challenges: The D3 MBSE Adoption Toolbox. *INCOSE International Symposium*, *28*(1), 1463–1477. https://doi.org/10.1002/j.2334-5837.2018.00561.x

Chami, M., & Bruel, J. (2018). A Survey on MBSE Adoption Challenges. *INCOSE Systems Engineering Conference of the Europe, Middle-East and Africa Sector EMEASEC*, *2018*(November).

Chandler, S. R., & Matthews, P. C. (2013). Through-life systems engineering design & support with SysML. *Procedia CIRP*, *11*, 425–430. https://doi.org/10.1016/j.procir.2013.07.002

Chapurlat, V., & Daclin, N. (2012). System interoperability: Definition and proposition of interface model in MBSE context. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *45*(6 PART 1), 1523–1528. https://doi.org/10.3182/20120523-3-RO-2023.00174

Checkland, P. (1981). Systems Thinking, Systems Practice. *John Wiley & Sons, Chichester*.

Checkland, P., & Poulter, J. (2010). Systems Approaches to Managing Change: A Practical Guide. In M. Reynolds & S. Holwell (Eds.), *Systems Approaches to Managing Change: A Practical Guide*. Springer London. https://doi.org/10.1007/978-1-84882-809-4

Chouali, S., Hammad, A., & Mountassir, H. (2013). Assembling components using SysML with non-functional requirements. *Electronic Notes in Theoretical Computer Science*, *295*, 31–47. https://doi.org/10.1016/j.entcs.2013.04.003

Churchman, C. W., & Ackoff, R. L. (1947). Towards an experimental measure of personality. *Psychological Review*, *54*(1), 41–51. https://doi.org/10.1037/h0061046

Churchman, C. W., & Ackoff, R. L. (1951). *Purposive Behavior and Cybernetics*. *29*(1), 32–39.

Churchman, C. W., Ackoff, R. L., Arnoff, E. L., Bhunia, A. K., Sahoo, L., & Shaikh, A. A. (1950). Introduction to Operations Research. In *Springer Optimization and Its Applications* (Vol. 153). Wiley. https://doi.org/10.1007/978-981-32-9967-2_1

Cloutier, R. (2015). Current Modeling Trends in Systems Engineering. *Insight*, *18*(2), 10–13. https://doi.org/10.1002/inst.12013

Cloutier, R., Sauser, B., Bone, M., & Taylor, A. (2015). Transitioning systems thinking to model-based systems engineering: Systemigrams to SysML models. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *45*(4), 662–674. https://doi.org/10.1109/TSMC.2014.2379657

Cole, B., Mittal, V., Gillespie, S., La, N., Wise, R., & Maccalman, A. (2019). Model-based systems engineering: Application and lessons from a technology maturation project. *Procedia Computer Science*, *153*, 202–209. https://doi.org/10.1016/j.procs.2019.05.071

Conway, M. E. (1968). How do committees invent. *Datamation*, *14*(4), 28–31.

Costa, B., Pires, P. F., & Delicato, F. C. (2020). Towards the adoption of OMG standards in the development of SOA-based IoT systems. *Journal of Systems and Software*, *169*, 110720. https://doi.org/10.1016/j.jss.2020.110720

Cressent, R., David, P., Idasiak, V., & Kratz, F. (2013). Designing the database for a reliability aware Model-Based System Engineering process. *Reliability Engineering and System Safety*, *111*, 171–182. https://doi.org/10.1016/j.ress.2012.10.014

Cresswell, K., Bokun, T., Mckinstry, B., & Procter, R. (n.d.). *Appendix B : Literature Review Methods Literature Tables*.

Dam, H. (2000). Origin and Evolution of Systems Engineering. *Systems Engineering*, *0*(July), 10–11.

Darpel, S., Beckman, S., Ferlin, T., Havenhill, M., Parrot, E., & Harcula, K. (2020). Method for tracking and communicating aggregate risk through the use of model-based systems engineering (MBSE) tools. *Journal of Space Safety Engineering*, *7*(1), 11–17. https://doi.org/10.1016/j.jsse.2020.01.001

Darwish, M., & Shehab, E. (2017). Framework for Engineering Design Systems Architectures Evaluation and Selection: Case Study. *Procedia CIRP*, *60*, 128–132. https://doi.org/10.1016/j.procir.2017.01.058

Davendralingam, N., & DeLaurentis, D. (2013). A robust optimization framework to architecting system of systems. *Procedia Computer Science*, *16*, 255–264. https://doi.org/10.1016/j.procs.2013.01.027

Davendralingam, N., DeLaurentis, D., Fang, Z., Guariniello, C., Han, S. Y., Marais, K., Mour, A., & Uday, P. (2014). An analytic workbench perspective to evolution of system of systems architectures. *Procedia Computer Science*, *28*, 702–710. https://doi.org/10.1016/j.procs.2014.03.084

David, P., Blanco, E., Revol, S., Noyrit, F., & Coatrine, M. (2019). Model based systems engineering introduction within industrial engineering curriculum. *Proceedings of the 21st International Conference on Engineering and Product Design Education: Towards a New Innovation Landscape, E and PDE 2019*, *September*. https://doi.org/10.35199/epde2019.70

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly: Management Information Systems*, *13*(3), 319–339. https://doi.org/10.2307/249008

Delp, C., Lam, D., Fosse, E., & Lee, C. Y. (2013). Model based document and report generation for systems engineering. *IEEE Aerospace Conference Proceedings*, 1–11. https://doi.org/10.1109/AERO.2013.6496926

Dent, M., Shield, S., Reeves, A., & Royston, J. (2017). Whose Line is it Anyway? Using MBSE in the Management and Acceptance of the Defence Lines of Development. *INCOSE International Symposium*, *27*(1), 1314–1326. https://doi.org/10.1002/j.2334-5837.2017.00430.x

Digby, J. (1990). Strategic thought at RAND, 1948-1963: The Ideas, Their Origins, Their Fates. In *RAND Corporation* (Issue N-3096-RC).

Do, Q., Cook, S., & Lay, M. (2014). An investigation of MBSE practices across the contractual boundary. *Procedia Computer Science*, *28*(Cser), 692–701. https://doi.org/10.1016/j.procs.2014.03.083

Do, Q., Cook, S., Fossnes, T., & Haskins, C. (2014). The Use of Models across the Contractual Boundary: Past, Present and Future. *INCOSE International Symposium*, *24*(1), 973–989. https://doi.org/10.1002/j.2334-5837.2014.tb03193.x

Do, Q., Cook, S., & Lay, M. (2014). An investigation of MBSE practices across the contractual boundary. *Procedia Computer Science*, *28*(Cser), 692–701. https://doi.org/10.1016/j.procs.2014.03.083

Do, Q., Lovric, B., & Cook, S. (2011). An MBSE feasibility study using the systems integration sandpit. *21st Annual International Symposium of the International Council on Systems Engineering, INCOSE 2011*, *1*, 518–528. https://doi.org/10.1002/j.2334-5837.2011.tb01222.x

Douglass, B. P. (2016). What Is Model-Based Systems Engineering? In *Agile Systems Engineering*. https://doi.org/10.1016/b978-0-12-802120-0.00001-1

Drack, M., Apfalter, W., & Pouvreau, D. (2007). On the making of a system theory of life: Paul A Weiss and Ludwig von Bertalanffy’s conceptual connection. In *Quarterly Review of Biology* (Vol. 82, Issue 4, pp. 349–373). https://doi.org/10.1086/522810

Drack, M., & Pouvreau, D. (2015). On the history of Ludwig von Bertalanffy’s “general systemology”, and on its relationship to cybernetics - Part III: Convergences and divergences. *International Journal of General Systems*, *44*(5), 523–571. https://doi.org/10.1080/03081079.2014.1000642

Ellis, K., Gregory, A., Mears-Young, B. R., & Ragsdell, G. (1995). *Critical Issues in Systems Theory and Practice* (K. Ellis, A. Gregory, B. R. Mears-Young, & G. Ragsdell (Eds.)). Springer US. https://doi.org/10.1007/978-1-4757-9883-8

Elphick, C. H., & Beer, S. (1981). Brain of the Firm. *The Journal of the Operational Research Society*, *32*(9). https://doi.org/10.2307/2581406

Estefan, J. A. (2008). Survey of Model-Based Systems Engineering (MBSE) Methodologies. *Jet Propulsion*.

Feldmann, S., Kernschmidt, K., & Vogel-Heuser, B. (2014). Combining a SysML-based modeling approach and semantic technologies for analyzing change influences in manufacturing plant models. *Procedia CIRP*, *17*, 451–456. https://doi.org/10.1016/j.procir.2014.01.140

Ferguson, R., Marshall, J., & Guzman, M. (2020). Adapting Progressive MBSE Development to Document Based Contracts. *IEEE Aerospace Conference Proceedings*, 1–11. https://doi.org/10.1109/AERO47225.2020.9172671

Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research*. Addison-Wesley. https://doi.org/10.1002/9781405186407.wbiecr017

Fisher, A., Nolan, M., Friedenthal, S., Loeffler, M., Sampson, M., Bajaj, M., VanZandt, L., Hovey, K., Palmer, J., & Hart, L. (2014). Model Lifecycle Management for MBSE. *INCOSE International Symposium*, *24*(1), 207–229. https://doi.org/10.1002/j.2334-5837.2014.tb03145.x

Fisher, G., & Walker, W. (1994). *Operations Research and the RAND Corporation*. https://www.rand.org/pubs/papers/P7857.html

Flood, R. L. (2000). A Brief Review of Peter B. Checkland's Contribution to Systemic Thinking. *Systemic Practice and Action Research*, *13*(6), 723–731. https://doi.org/10.1023/A:1026423411383

For, G., Cs, A., Ias, R. E. L., & Chniques, I. T. S. T. E. (n.d.). Avionics Reliability, Its Techniques and Related Disciplines. In *AGARD Conference Proceedings* (Issue 261).

Forrester, J. W. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review*, *10*(2–3), 245–256. https://doi.org/10.1002/sdr.4260100211

Fosse, E., Harmon, C., Lefland, M., Castillo, R., & Devereaux, A. (2015). Inheriting curiosity: Leveraging MBSE to build Mars2020. *AIAA SPACE 2015 Conference and Exposition*. https://doi.org/10.2514/6.2015-4617

Friedenthal, S., Moore, A., & Steiner, R. (2015). Deploying SysML in an Organization. *A Practical Guide to SysML*, 543–554. https://doi.org/10.1016/b978-0-12-800202-5.00019-9

Frosch, R. A. (1993). A Classic Look at Systems Engineering. In F. T. Hoban & W. M. Lawbaugh (Eds.), *Readings in Systems Engineering*. National Aeronautics and Space Administration.

Gao, S., Cao, W., Fan, L., & Liu, J. (2019). MBSE for satellite communication system architecting. *IEEE Access*, *7*, 164051–164067. https://doi.org/10.1109/ACCESS.2019.2952889

Garro, A., & Tundis, A. (2012). A model-based method for system reliability analysis. *Simulation Series*, *44*(4 BOOK), 126–133.

Gianni, D., D'Ambrogio, A., & Tolk, A. (2001). *Modeling and Simulation-Based Systems Engineering Handbook*. https://doi.org/10.1002/inst.2001428

Gilbert, D., Yearworth, M., & Oliver, L. (2014). Systems approach to the development and application of technical metrics to Systems Engineering projects. *Procedia Computer Science*, *28*(Cser), 71–80. https://doi.org/10.1016/j.procs.2014.03.010

Golafshani, N. (2015). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2003.1870

Graignic, P., Vosgien, T., Jankovic, M., Tuloup, V., Berquet, J., & Troussier, N. (2013). Complex system simulation: Proposition of a MBSE framework for design-analysis integration. *Procedia Computer Science*, *16*, 59–68. https://doi.org/10.1016/j.procs.2013.01.007

Gregory, J., Berthoud, L., Tryfonas, T., Rossignol, A., & Faure, L. (2020). The long and winding road: MBSE adoption for functional avionics of spacecraft. *Journal of Systems and Software*, *160*, 110453. https://doi.org/10.1016/j.jss.2019.110453

Hair, J. F., Howard, M. C., & Nitzl, C. (2020). Assessing measurement model quality in PLS-SEM using confirmatory composite analysis. *Journal of Business Research*, *109*(August 2019), 101–110. https://doi.org/10.1016/j.jbusres.2019.11.069

Hale, J. P., Zimmerman, P., Kukkala, G., Kobryn, P., Puchek, B., Bisconti, M., Baldwin, C., & Mulpuri, M. (2017). *Digital Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion*. *July*. http://www.sti.nasa.gov

Hall, A. D. (1962). A Methodology for Systems Engineering. In *Princeton, New Jersey: Van Nostrand*.

Hambly, M. (2003). Should I stay or should I go? *Working with Older People*, *7*(2), 16–20. https://doi.org/10.1108/13663666200300019

Haskins, C. (2011). A historical perspective of MBSE with a view to the future. *21st Annual International Symposium of the International Council on Systems Engineering, INCOSE 2011*, *1*, 488–504. https://doi.org/10.1002/j.2334-5837.2011.tb01220.x

Hause, M., Buitelaar, J., van de Ven, M., & Burgers, E. (2015). The Use of MBSE in Infrastructure Projects -- An MBSE Challenge Team Paper. *INCOSE*

International Symposium, *25*(1), 371–387. https://doi.org/10.1002/j.2334-5837.2015.00069.x

Hermann, E., Ávila, R. B., Navaux, P. O. A., & Denneulin, Y. (2012). MODELS Journal - 2012. In *Vecpar* (Vol. 4395).

Hernandez, C., Rodriguez, M., Diaz, I., & Sanz, R. (2016). Model Based Engineering of Process Plants using SysML. In *Computer Aided Chemical Engineering* (Vol. 38, Issue 2014). Elsevier Masson SAS. https://doi.org/10.1016/B978-0-444-63428-3.50218-6

Heylighen, F. (2001). Cybernetics and Second-Order Cybernetics. *Encyclopedia of Physical Science & Technology*, 1–24. http://www.nomads.usp.br/pesquisas/design/objetos_interativos/arquivos/restrito/heylighen_Cybernetics and Second-Order Cybernetics.pdf

Hoag, M. W. (1956). An Introduction to Systems Analysis. In *U. S. Air Force* (Issue RM-1678). https://doi.org/10.1007/978-1-349-18143-8_13

Holladay, J. B., Knizhnik, J., Weiland, K. J., Stein, A., Sanders, T., & Schwindt, P. (2019). MBSE Infusion and Modernization Initiative (MIAMI): "Hot" Benefits for Real NASA Applications. *IEEE Aerospace Conference Proceedings*, *2019-March*, 1–14. https://doi.org/10.1109/AERO.2019.8741795

Honour, E. C. (1998). INCOSE: History of the international council on systems engineering. *Systems Engineering*, *1*(1), 4–13. https://doi.org/10.1002/(SICI)1520-6858(1998)1:1<4::AID-SYS2>3.0.CO;2-M

Huldt, T., & Stenius, I. (2019). State-of-practice survey of model-based systems engineering. *Systems Engineering*, *22*(2), 134–145. https://doi.org/10.1002/sys.21466

INCOSE. (2017). *Systems Engineering Handbook* (Vol. 5, Issue 1).

INCOSE. (2015). Introduction to Model-Based Systems Engineering (MBSE) and SysML. *Federation Proceedings*, *7*(1), 26.

INCOSE. (2015). Systems Engineering Handbook A Guide for System Life Cycle Processes and Activities. In *Systems engineering handbook: A guide for system life cycle processes and activities* (Issue August). http://dl.acm.org/citation.cfm?id=552393

INCOSE. (2014). *A World in Motion - Systems Engineering Vision 2025*. https://doi.org/10.1126/science.327.5970.1183-d

Inkermann, D. (2019). Towards model-based process engineering. *Proceedings of the International Conference on Engineering Design, ICED*, *2019-Augus*(AUGUST), 3741–3750. https://doi.org/10.1017/dsi.2019.381

International Council on Systems Engineering (INCOSE). (2007). Systems Engineering Vision 2020. *Systems Engineering Vision 2020*.

Jackson, M. C. (1982). Nature of Soft Systems Thinking: The Work of Churchman, Ackoff an. *Journal of Applied Systems Analysis*, *9*, 17–39.

Jackson, M. C. (1985). Social systems theory and practice: The need for a critical approach. *International Journal of General Systems*, *10*(2–3). https://doi.org/10.1080/03081078508934877

Jackson, M. C. (2001). Critical systems thinking and practice. *European Journal of Operational Research*, *128*(2), 233–244. https://doi.org/10.1016/S0377-2217(00)00067-9

Karban, R., Andolfato, L., Bristow, P., Chiozzi, G., Esselborn, M., Schilling, M., Schmid, C., Sommer, H., & Zamparelli, M. (2014). Model based systems engineering for astronomical projects. *Modeling, Systems Engineering, and Project Management for Astronomy VI*, *9150*(August 2014), 91500L. https://doi.org/10.1117/12.2055540

Kaslow, D., Ayres, B., Cahill, P. T., & Hart, L. (2018). A model-based systems engineering approach for technical measurement with application to a CubeSat. *IEEE Aerospace Conference Proceedings*, *2018-March*, 1–10. https://doi.org/10.1109/AERO.2018.8396443

Knizhnik, J. R. L., Jones-mcdowall, K., Weiland, K. J., Holladay, J. B., & Grondin, T. (n.d.). *An Exploration of Lessons Learned from NASA' s MBSE Infusion and Modernization Initiative (MIAMI).*

Köhler, W. (1967). Gestalt Psychology. *Psychologische Forschung*, *31*(4), 358–379. https://doi.org/10.5840/newscholas194317445

Krupa, G. P. (2019). Application of agile model-based systems engineering in aircraft conceptual design. *Aeronautical Journal*, *123*(1268), 1561–1601. https://doi.org/10.1017/aer.2019.53

Kuhn, A., Murphy, G. C., & Thompson, C. A. (2012). An exploratory study of forces and frictions affecting large-scale model-driven development. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7590 LNCS*(Models), 352–367. https://doi.org/10.1007/978-3-642-33666-9_23

Lai, P. (2017). The Literature Review of Technology Adoption Models and Theories for the Novelty Technology. *Journal of Information Systems and Technology Management*, *14*(1), 21–38. https://doi.org/10.4301/s1807-17752017000100002

Laing, C., David, P., Blanco, E., & Dorel, X. (2020). Questioning integration of verification in model-based systems engineering: an industrial perspective⋆. In

Computers in Industry (Vol. 114). https://doi.org/10.1016/j.compind.2019.103163

Landers, T. F. R. (2014). *Practical Implementation of Model Based Systems Development Biography*. *February*, 1–25.

Lemazurier, L., Chapurlat, V., & Grossetête, A. (2017). An MBSE Approach to Pass from Requirements to Functional Architecture. *IFAC-PapersOnLine*, *50*(1), 7260–7265. https://doi.org/10.1016/j.ifacol.2017.08.1376

Long, D., & Scott. (1998). Understanding the fraud and abuse laws: Guidance for internists. In *Annals of Internal Medicine* (Vol. 128, Issue 8). https://doi.org/10.7326/0003-4819-128-8-199804150-00012

Madni, A. M., & Sievers, M. (2018). Model-based systems engineering: Motivation, current status, and research opportunities. *Systems Engineering*, *21*(3), 172–190. https://doi.org/10.1002/sys.21438

Maheshwari, A. (2015). *Industrial Adoption of Model-Based Systems Engineering: Challenges and Strategies*. *January*.

Maheshwari, A., Davendralingam, N., Raz, A. K., & Delaurentis, D. A. (2018). Developing Model-Based Systems Engineering Artifacts for Legacy Systems. *AIAA Aerospace Sciences Meeting*, *2018*, *210059*. https://doi.org/10.2514/6.2018-1213

Malone, R., Friedland, B., Herrold, J., & Fogarty, D. (2016). Insights from Large Scale Model Based Systems Engineering at Boeing. *INCOSE International Symposium*, *26*(1), 542–555. https://doi.org/10.1002/j.2334-5837.2016.00177.x

Marshall, G. C., Hale, J. P., Zimmerman, P., Kukkala, G., Kobryn, P., Puchek, B., Bisconti, M., Baldwin, C., & Mulpuri, M. (2017). *Digital Model-Based Engineering: Expectations, Prerequisites, and Challenges of Infusion*. *July*. http://www.sti.nasa.gov

Martin, N. M. (1960). Stafford Beer. Cybernetics and management. Management science series. John Wiley & Sons, Inc., New York1959, xviii + 214 pp. *Journal of Symbolic Logic*, *25*(3), 258–258. https://doi.org/10.2307/2964690

Martland, C. D. (2013). Encyclopedia of Operations Research and Management Science. In *Encyclopedia of Operations Research and Management Science*. https://doi.org/10.1007/978-1-4419-1153-7

Maskey, R., Fei, J., & Nguyen, H. O. (2018). Use of exploratory factor analysis in maritime research. *Asian Journal of Shipping and Logistics*, *34*(2), 91–111. https://doi.org/10.1016/j.ajsl.2018.06.006

Mhenni, F., Choley, J. Y., Penas, O., Plateaux, R., & Hammadi, M. (2014). A SysML-based methodology for mechatronic systems architectural design. *Advanced Engineering Informatics*, *28*(3), 218–231. https://doi.org/10.1016/j.aei.2014.03.006

Micouin, P. (2014). Model-Based Systems Engineering: Fundamentals and Methods. In *Model-Based Systems Engineering: Fundamentals and Methods* (Vol. 9781848214). https://doi.org/10.1002/9781118579435

Mohagheghi, P. (2010). An Approach for Empirical Evaluation of Model- Driven Engineering in Multiple Dimensions. *Work*, *2006*, 1–10. http://sintef.com/upload/IKT/9012/ECMFA10-C2M-Evaluating-MDE-final.pdf

Mohagheghi, P., & Dehlen, V. (2008). Where is the proof? - A review of experiences from applying MDE in industry. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *5095 LNCS*, 432–443. https://doi.org/10.1007/978-3-540-69100-6-31

Mohagheghi, P., Gilani, W., Stefanescu, A., & Fernandez, M. A. (2013). An empirical study of the state of the practice and acceptance of model-driven engineering in four industrial cases. *Empirical Software Engineering*, *18*(1), 89–116. https://doi.org/10.1007/s10664-012-9196-x

Montgomery, P. R. (2013). Model-based system integration (MBSI) - Key attributes of MBSE from the system integrator’s perspective. *Procedia Computer Science*, *16*, 313–322. https://doi.org/10.1016/j.procs.2013.01.033

Morkevicius, A. (2014). *Integrated modeling: Adopting Architecture Frameworks for Model-based Systems Engineering*.

Morkevicius, A., Aleksandraviciene, A., Mazeika, D., Bisikirskiene, L., & Strolia, Z. (2017). MBSE Grid: A Simplified SysML-Based Approach for Modeling Complex Systems. *INCOSE International Symposium*, *27*(1), 136–150. https://doi.org/10.1002/j.2334-5837.2017.00350.x

Morkevicius, A., Bisikirskiene, L., & Jankevicius, N. (2016). We choose MBSE: What’s next? *Proceedings of the 6th International Conference on Complex Systems Design and Management, CSD and M 2015*, *2016-Janua*, 313. https://doi.org/10.1007/978-3-319-26109-6_36

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification Strategies for Establishing Reliability and Validity in Qualitative Research. *International Journal of Qualitative Methods*, *1*(2), 13–22. https://doi.org/10.1177/160940690200100202

Moser, C. A., & Kalton, G. (2017). Survey Methods in Social Investigation. In *Survey Methods in Social Investigation*. Routledge. https://doi.org/10.4324/9781315241999

Mousavi, B. A., Azzouz, R., Heavey, C., & Ehm, H. (2019). A survey of model-based system engineering methods to analyse complex supply chains: A case study in semiconductor supply chain. *IFAC-PapersOnLine*, *52*(13), 1254–1259. https://doi.org/10.1016/j.ifacol.2019.11.370

Nastov, B., Chapurlat, V., Pfister, F., & Dony, C. (2017). MBSE and V&V: a tool-equipped method for combining various V&V strategies. *IFAC-PapersOnLine*, *50*(1), 10538–10543. https://doi.org/10.1016/j.ifacol.2017.08.1309

Nielsen, C. B., Larsen, P. G., & Fitzgerald, J. (2003). System of Systems Engineering: Basic Concepts, Model-Based Techniques, and Research Directions. *EMJ - Engineering Management Journal*, *15*(3), 36–45. https://doi.org/10.1145/2794381

Nielsen, C. B., Larsen, P. G., Fitzgerald, J., Woodcock, J., & Peleska, J. (2015). Systems of systems engineering: Basic concepts, model-based techniques, and research directions. *ACM Computing Surveys*. https://doi.org/10.1145/2794381

Noguchi, R. A. (2019). A Roadmap for Advancing the State of the Practice of Model Based Systems Engineering for Government Acquisition. *INCOSE International Symposium*, *29*(1), 678–690. https://doi.org/10.1002/j.2334-5837.2019.00628.x

Othman, M. A. Bin, Heng, T. C., & Hin, O. S. (2016). Establishment of model-based systems engineering approach for rapid transit system operation analysis. In *Advances in Intelligent Systems and Computing* (Vol. 426, pp. 159–169). https://doi.org/10.1007/978-3-319-29643-2_12

Papke, B. L., Wang, G., Kratzke, R., & Schreiber, C. (2020). Implementing MBSE – An Enterprise Approach to an Enterprise Problem. *INCOSE International Symposium*, *30*(1), 1539–1556. https://doi.org/10.1002/j.2334-5837.2020.00803.x

Pavalkis, S. (2016). Towards Industrial Integration of MBSE into PLM for Mission-Critical Systems. *INCOSE International Symposium*, *26*(1), 2462–2477. https://doi.org/10.1002/j.2334-5837.2016.00306.x

Paxson, E. (1950). *Strategic Bombing Systems Analysis*. RAND Corporation.

Pouvreau, D. (2014). On the history of Ludwig von Bertalanffys "general systemology", and on its relationship to cybernetics-Part II: Contexts and developments of the systemological hermeneutics instigated by von Bertalanffy. *International Journal of General Systems*, *43*(2), 172–245. https://doi.org/10.1080/03081079.2014.883743

Pouvreau, D., & Drack, M. (2007). On the history of Ludwig von Bertalanffy's "general Systemology", and on its relationship to cybernetics. *International Journal of General Systems, 36*(3), 281–337. https://doi.org/10.1080/03081070601127961

Ramage, M., & Shipp, K. (2009). Systems thinkers. In *Systems Thinkers*. https://doi.org/10.1007/978-1-84882-525-3

Ramos, A. L., Ferreira, J. V., & Barceló, J. (2012). Model-based systems engineering: An emerging approach for modern systems. *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews, 42*(1), 101–111. https://doi.org/10.1109/TSMCC.2011.2106495

Rogers, E. M. (1995). Diffusion of Innovations. In *An Integrated Approach to Communication Theory and Research*. Routledge. https://doi.org/10.4324/9780203710753-35

Russell, M. (2012). Using MBSE to enhance system design decision making. *Procedia Computer Science, 8*, 188–193. https://doi.org/10.1016/j.procs.2012.01.041

Salado, A. (2013). Efficient and effective systems integration and verification planning using a model-centric environment. *23rd Annual International Symposium of the International Council on Systems Engineering, INCOSE 2013, 2*(Estefan 2008), 1244–1258. https://doi.org/10.1002/j.2334-5837.2013.tb03078.x

Schöberl, M., Rebentisch, E., Trauer, J., Mörtl, M., & Fottner, J. (2020). Evaluating Mbse Potential Using Product and Development Characteristics – a Statistical Investigation. *Proceedings of the Design Society: DESIGN Conference*, *1*, 2385–2394. https://doi.org/10.1017/dsd.2020.277

Schreiber, J. B., Stage, F. K., King, J., Nora, A., & Barlow, E. A. (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. *Journal of Educational Research, 99*(6), 323–338. https://doi.org/10.3200/JOER.99.6.323-338

Selic, B. (2008). Personal reflections on automation, programming culture, and model-based software engineering. *Automated Software Engineering, 15*(3-4 SPEC. ISS.), 379–391. https://doi.org/10.1007/s10515-008-0035-7

Selic, B. (2012). What will it take? A view on adoption of model-based methods in practice. *Software and Systems Modeling*, *11*(4), 513–526. https://doi.org/10.1007/s10270-012-0261-0

Sieniutycz, S. (2020). Systems science vs cybernetics. *Complexity and Complex Thermo-Economic Systems*, 1–8. https://doi.org/10.1016/b978-0-12-818594-0.00001-5

Sillitto, H., Griego, R., Arnold, E., Dori, D., Martin, J., McKinney, D., Godfrey, P., Krob, D., & Jackson, S. (2018). What do we mean by “system”? - System Beliefs and Worldviews in the INCOSE Community. *INCOSE International Symposium*, *28*(1), 1190–1206. https://doi.org/10.1002/j.2334-5837.2018.00542.x

Skavhaug, A., Guiochet, J., Schoitsch, E., & Bitsch, F. (2016). *Computer Safety, Reliability, and Security: SAFECOMP 2016 Workshops, ASSURE, DECSoS, SASSUR, and TIPS, Trondheim, Norway, September 20, 2016, Proceedings*. http://dx.doi.org/10.1007/978-3-319-45480-1

Sousa-Poza, A., Keating, C., & Kovacic, S. (2015). Systems engineering: evolution and challenges. *International Journal of System of Systems Engineering*, *5*(4), 379–399. https://doi.org/10.1504/IJSSE.2014.067104

Steimer, C., Fischer, J., & Aurich, J. C. (2017). Model-based Design Process for the Early Phases of Manufacturing System Planning using SysML. *Procedia CIRP*, *60*, 163–168. https://doi.org/10.1016/j.procir.2017.01.036

Strawn, G., & Strawn, C. (2017). Norbert Wiener: Mastermind of Cybernetics. *IT Professional*, *19*(5), 58–60. https://doi.org/10.1109/MITP.2017.3680955

Suryadevara, J., & Tiwari, S. (2018). Adopting MBSE in Construction Equipment Industry: An Experience Report. *Proceedings - Asia-Pacific Software Engineering Conference, APSEC*, *2018-Decem*, 512–521. https://doi.org/10.1109/APSEC.2018.00066

Sürücü, L., & Maslakçı, A. (2020). Validity and Reliability in Quantitative Research. *Business & Management Studies: An International Journal*, *8*(3), 2694–2726. https://doi.org/10.15295/bmij.v8i3.1540

Taherdoost, H. (2018). A review of technology acceptance and adoption models and theories. *Procedia Manufacturing*, *22*, 960–967. https://doi.org/10.1016/j.promfg.2018.03.137

Tarhini, A., Elyas, T., Akour, M. A., & Al-Salti, Z. (2016). Technology, Demographic Characteristics and E-Learning Acceptance: A Conceptual Model Based on Extended Technology Acceptance Model. *Higher Education Studies*, *6*(3), 72. https://doi.org/10.5539/hes.v6n3p72

Tsadimas, A. (2015). Model-based enterprise information system architectural design with SysML. *Proceedings - International Conference on Research Challenges in Information Science*, *2015-June*(June), 492–497. https://doi.org/10.1109/RCIS.2015.7128911

Tschirner, C., Bretz, L., Dumitrescu, R., & Gausemeier, J. (2015). Applying Model-Based Systems Engineering for Product Engineering Management concepts for industrial application. *1st IEEE International Symposium on Systems*

Engineering, ISSE 2015 - Proceedings, 42–49. https://doi.org/10.1109/SysEng.2015.7302510

Urbieta, M., Antonelli, L., Rossi, G., & do Prado Leite, J. C. S. (2020). The impact of using a domain language for an agile requirement management. *Information and Software Technology*, *127*(June). https://doi.org/10.1016/j.infsof.2020.106375

Van Noten, J., Gadeyne, K., & Witters, M. (2017). Model-based Systems Engineering of Discrete Production Lines Using SysML: An Experience Report. *Procedia CIRP*, *60*, 157–162. https://doi.org/10.1016/j.procir.2017.01.018

Venkatesh, V., & Davis, F. D. (1996). A Model of the Antecedents of Perceived Ease of Use: Development and Test. *Decision Sciences*, *27*(3), 451–481. https://doi.org/10.1111/j.1540-5915.1996.tb00860.x

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, *27*(3), 425–478. https://doi.org/10.2307/30036540

Vogelsang, A., Amorim, T., Pudlitz, F., Gersing, P., & Philipps, J. (2017). Should i stay or should i go?: On forces that drive and prevent mbse adoption in the embedded systems industry. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *10611 LNCS*, 182–198. https://doi.org/10.1007/978-3-319-69926-4_14

Vogelsang, A., Eder, S., Hackenberg, G., Junker, M., & Teufl, S. (2014). Supporting concurrent development of requirements and architecture: A model-based approach. *MODELSWARD 2014 - Proceedings of the 2nd International Conference on Model-Driven Engineering and Software Development*, 587–595. https://doi.org/10.5220/0004709305870595

Vogelsang, K., Steinhüser, M., & Hoppe, U. (2013). A qualitative approach to examine technology acceptance. *International Conference on Information Systems (ICIS 2013): Reshaping Society Through Information Systems Design*, *1*, 234–245.

Von Bertalanffy, L. (1950). The theory of open systems in physics and biology. In *Science*. https://doi.org/10.1126/science.111.2872.23

Von Bertalanffy, L. (1972). The History and Status of General Systems Theory. *The Academy of Management Journal*, *15*(4), 407–426.

Von Bertalanffy, L. (1973). *General Systems Theory: Foundations, Development, Applications* (G. Braziller (Ed.); illustrate). Braziller, 2003.

Walden, D. D., Roedler, G. J., & Forsberg, K. (2014). Introducing the INCOSE Systems Engineering Handbook Version 4. *INCOSE International Symposium*, *24*(s1), 578–580. https://doi.org/10.1002/j.2334-5837.2014.00042.x

Wang, L., Izygon, M., Okon, S., Garner, L., & Wagner, H. (2016). Effort to accelerate MBSE adoption and usage at JSC. *AIAA Space and Astronautics Forum and Exposition, SPACE 2016*, 1–10. https://doi.org/10.2514/6.2016-5542

Watson, M. D. (2019). Systems Engineering Principles and Hypotheses. *Insight*, *22*(1), 18–28. https://doi.org/10.1002/inst.12233

Weaver, W. (1948). Science and Complexity. In *American Scientist: Vol. 36(4)* (Issues 536–544). https://doi.org/10.1201/9781315383132

Weaver, W. (1949). Recent contributions to the mathematical theory of communication. In C. Shannon (Ed.), *The mathematical theory of communication* (pp. 1–12). University of Illinois Press.

White, C. J., & Mesmer, B. L. (2020). Research needs in systems engineering: Report from a University of Alabama in Huntsville workshop. *Systems Engineering*, *23*(2), 154–164. https://doi.org/10.1002/sys.21501

Wibben, D. R., & Furfaro, R. (2015). Model-Based Systems Engineering approach for the development of the science processing and operations center of the NASA OSIRIS-REx asteroid sample return mission. *Acta Astronautica*, *115*, 147–159. https://doi.org/10.1016/j.actaastro.2015.05.016

Wiener, N. (1948). *Cybernetics, or control and communication in the animal and the machine* (Second Edi). The MIT Press. https://doi.org/10.1037/13140-000

Wilking, F., Schleich, B., & Wartzack, S. (2020). MBSE along the Value Chain - An Approach for the Compensation of additional Effort. *SOSE 2020 - IEEE 15th International Conference of System of Systems Engineering, Proceedings*, 61–66. https://doi.org/10.1109/SoSE50414.2020.9130497

Winter, M., & Checkland, P. (2003). Soft systems : a fresh perspective for project management conventional project management theory represents a particular image of project management practice rather than an all- encompassing theory. *Civil Engineering*, *156*, 187–192.

WIPO. (2020). Global Innovation Index 2020. In *Economy Reports & Analysis*. https://www.globalinnovationindex.org/analysis-economy%0Ahttps://www.globalinnovationindex.org/gii-2020-report#

Wu, Q., Gouyon, D., Levrat, E., & Boudau, S. (2020). Use of Patterns for Know-How Reuse in a Model-Based Systems Engineering Framework. *IEEE Systems Journal*, 1–12. https://doi.org/10.1109/jsyst.2020.2975116

Wu, Q., Gouyon, D., Levrat, É., & Boudau, S. (2019). A Review of Know-How Reuse with Patterns in Model-Based Systems Engineering. In *Complex Systems Design & Management* (pp. 219–229). https://doi.org/10.1007/978-3-030-04209-7_18

Wymore, A. W. (1993). *Model-Based Systems Engineering: An Introduction to the Mathematical Theory of Discrete Systems and to the Tricotyledon Theory of System Design* (illustrate). CRC Press.

Yang, L., Cormican, K., & Yu, M. (2019). Ontology-based systems engineering: A state-of-the-art review. *Computers in Industry*, *111*, 148–171. https://doi.org/10.1016/j.compind.2019.05.003

APPENDICES

APPENDIX A

EXPERT PANEL ANALYSIS RESULTS

Construct	Frequency in the Literature	E1	E2	E3	E4	E5	E6	E7	E8	Number of Agreed Experts
Perceived Value and Inertial Issues	11	A	A	NA	A	A	A	A	A	7
Tools and Methodologies Issues	10	A	A	NA	A	A	A	NA	A	6
Improvements in Communication and Understanding	7	A	A	A	A	NA	A	A	A	7
Complexity Management	7	A	A	A	NA	A	NA	A	A	6
Cost / Return on Investment Issues	6	A	A	A	NA	A	NA	NA	A	5
Awareness and Maturity Issues	6	A	A	A	A	A	NA	A	NA	6
Modifiability and Modularity	5	NA	A	A	A	NA	NA	A	NA	4
Improved Knowledge Sharing	4	NA	NA	A	NA	NA	A	NA	A	3
Lack of Appropriately Trained Practitioners	4	A	A	NA	NA	NA	NA	NA	NA	2
Comprehensive Support of SE Life-Cycle Activities	2	NA	NA	A	NA	NA	NA	A	NA	2

APPENDIX B

PILOT STUDY RELIABILITY ANALYSIS RESULTS

Reliability Statistics – Behavioral Intention				
Cronbach's Alpha	**0,780**			
N of Items	**5**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
BI1	16,35	6,285	,353	,797
BI2	16,30	5,138	,585	,728
BI3	16,33	5,251	,528	,749
BI4	16,40	5,169	,686	,696
BI5	16,33	5,148	,635	,711
Verdict	No action taken.			

Reliability Statistics – Perceived Usefulness				
Cronbach's Alpha	**0,743**			
N of Items	**5**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
PU1	16,30	4,626	,483	,706
PU2	16,28	4,461	,526	,690
PU3	16,30	4,985	,390	,738
PU4	16,23	4,230	,621	,653
PU5	16,20	4,472	,512	,695
Verdict	No action taken.			

Reliability Statistics – Perceived Ease of Use				
Cronbach's Alpha	**0,879**			
N of Items	**5**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
PEU1	15,90	9,887	,763	,841
PEU2	15.97	9,563	,844	,822
PEU3	15,85	10,900	,569	,886
PEI4	16,08	10,071	,685	,860
PEU5	16,10	10,041	,708	,854
Verdict	No action taken.			

Reliability Statistics – Improvements in Communication and Understanding				
Cronbach's Alpha	**0,620**			
N of Items	**5**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ICU1	15,88	4,779	,482	,522
ICU2	16,13	4,830	,279	,619
ICU3	16,43	4,661	,228	,667
ICU4	15,85	4,438	,599	,465
ICU5	15,83	4,917	,406	,554
Verdict	ICU3 was eliminated.			
Reliability Statistics – Improvements in Communication and Understanding				
Cronbach's Alpha	**0,667**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ICU1	12,28	2,871	,548	,539
ICU2	12,53	2,871	,321	,706
ICU4	12,25	2,810	,512	,560
ICU5	12,23	2,999	,454	,596
Verdict	No action taken.			

Reliability Statistics – Complexity Management				
Cronbach's Alpha	**0,646**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
CM1	11,63	4,548	,166	,741
CM2	11,58	3,276	,640	,426
CM3	11,83	3,738	,472	,548
CM4	11,63	3,266	,480	,538
Verdict	CM1 was eliminated.			
Reliability Statistics – Complexity Management				
Cronbach's Alpha	**0,741**			
N of Items	**3**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
CM2	7,65	2,285	,625	,591
CM3	7,90	2,503	,534	,694
CM4	7,70	2,062	,554	,683
Verdict	No action taken.			

Reliability Statistics – Tools and Methodologies Issues				
Cronbach's Alpha	**0,778**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
TM1	6,67	4,687	,594	,720
TM2	6,92	4,687	,641	,699
TM3	6,95	4,613	,512	,764
TM4	6,67	4,276	,600	,717
Verdict	No action taken.			

Reliability Statistics – Return on Investment Issues				
Cronbach's Alpha	**0,525**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ROI1	7,00	2,718	,477	,281
ROI2	7,00	3,487	,330	,440
ROI3	7,12	3,035	,460	,315
ROI4	7,15	4,644	,020	,656
Verdict	ROI4 was eliminated.			
Reliability Statistics – Return on Investment Issues				
Cronbach's Alpha	**0,656**			
N of Items	**3**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
ROI1	4,72	1,999	,569	,405
ROI2	4,72	2,769	,382	,663
ROI3	4,85	2,490	,460	,567
Verdict	No action taken.			

Reliability Statistics – Perceived Value and Inertial Issues				
Cronbach's Alpha	**0,781**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
PV1	6,98	4,897	,575	,735
PV2	7,05	5,844	,498	,770
PV3	6,85	5,105	,604	,718
PV4	6,88	4,676	,677	,678
Verdict	No action taken.			

Reliability Statistics – Awareness and Maturity Issues				
Cronbach's Alpha	**0,690**			
N of Items	**4**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
AM1	7,45	5,177	,512	,600
AM2	6,93	5,815	,242	,781
AM3	7,58	4,804	,668	,505
AM4	7,58	5,020	,535	,585
Verdict	AM2 was eliminated.			
Reliability Statistics – Awareness and Maturity Issues				
Cronbach's Alpha	**0,781**			
N of Items	**3**			
Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
AM1	4,60	3,118	,511	,816
AM3	4,53	2,717	,731	,581
AM4	4,73	2,769	,624	,696
Verdict	No action taken.			

APPENDIX C

MEAN 5% TRUNCATED MEAN VALUES

	N Statistic	Mean Statistic	5% Trimmed Mean		N Statistic	Mean Statistic	5% Trimmed Mean
BI1	91	3,85	3,88	**CM2**	91	3,87	3,93
BI2	91	3,98	4,04	**CM3**	91	3,66	3,73
BI3	91	3,95	3,98	**CM4**	91	3,67	3,73
BI4	91	3,96	3,98	**TM1**	91	2,46	2,40
BI5	91	3,59	4,06	**TM2**	91	2,40	2,35
PU1	91	3,88	3,59	**TM3**	91	2,55	2,84
PU2	91	3,99	3,92	**TM4**	91	2,70	2,96
PU3	91	3,72	4,02	**ROI1**	91	2,78	2,77
PU4	91	3,86	3,76	**ROI2**	91	2,80	2,78
PU5	91	3,77	3,90	**ROI3**	91	2,89	2,88
PEU1	91	3,85	3,77	**PV1**	91	2,14	2,10
PEU2	91	3,95	3,91	**PV2**	91	2,13	2,10
PEU3	91	3,96	4,00	**PV3**	91	2,04	2,02
PEU4	91	3,91	4,00	**PV4**	91	2,14	2,12
PEU5	91	3,93	3,95	**AM1**	91	2,28	2,25
ICU1	91	3,88	3,96	**AM3**	91	2,56	2,53
ICU2	91	3,93	3,99	**AM4**	91	2,60	2,57
ICU4	91	3,85	3,95				
ICU5	91	3,98	3,96				
Valid N (listwise)	91						

APPENDIX D

DESCRIPTIVE STATISTICS

	N	Mean		Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Std. Error
BI1	93	3,85	,088	,846	-,145	,250	-,788	,495
BI2	93	3,98	,099	,955	-,492	,250	-,475	,495
BI3	94	3,95	,087	,847	-,548	,249	,362	,493
BI4	94	3,96	,096	,926	-,412	,249	-,452	,493
BI5	94	4,01	,096	,933	-,589	,249	-,214	,493
PU1	94	3,59	,114	1,101	-,196	,249	-,901	,493
PU2	94	3,88	,107	1,035	-,533	,249	-,629	,493
PU3	94	3,99	,109	1,052	-,714	,249	-,483	,493
PU4	94	3,72	,104	1,010	-,313	,249	-,699	,493
PU5	94	3,86	,110	1,064	-,540	,249	-,713	,493
PEU1	94	3,77	,091	,885	-,089	,249	-,847	,493
PEU2	94	3,85	,098	,950	-,387	,249	-,440	,493
PEU3	94	3,95	,092	,896	-,260	,249	-1,002	,493
PEU4	94	3,96	,096	,926	-,246	,249	-1,167	,493
PEU5	94	3,89	,090	,873	-,185	,249	-,923	,493
ICU1	94	3,91	,089	,863	-,243	,249	-,826	,493
ICU2	94	3,93	,089	,858	-,272	,249	-,771	,493
ICU4	94	3,88	,097	,937	-,562	,249	-,120	,493
ICU5	94	3,93	,083	,806	-,240	,249	-,616	,493
CM2	94	3,87	,106	1,029	-,646	,249	-,177	,493
CM3	94	3,66	,114	1,103	-,465	,249	-,565	,493
CM4	94	3,67	,131	1,273	-,822	,249	-,264	,493
TM1	94	2,46	,125	1,215	,414	,249	-,885	,493
TM2	94	2,40	,131	1,273	,635	,249	-,672	,493
TM3	94	2,55	,128	1,241	,359	,249	-,884	,493
TM4	94	2,70	,122	1,181	,163	,249	-,897	,493
ROI1	94	2,78	,114	1,109	,167	,249	-,495	,493
ROI2	94	2,80	,113	1,093	,111	,249	-,576	,493

ROI3	94	2,89	,125	1,213	,097	,249	-,796	,493
PV1	94	2,14	,099	,957	,318	,249	-,925	,493
PV2	94	2,13	,095	,919	,337	,249	-,777	,493
PV3	94	2,04	,092	,891	,475	,249	-,552	,493
PV4	94	2,14	,092	,887	,289	,249	-,722	,493
AM1	93	2,28	,106	1,025	,462	,250	-,372	,495
AM3	94	2,56	,106	1,032	-,055	,249	-,889	,493
AM4	94	2,60	,111	1,081	-,018	,249	-,883	,493
Valid N (listwise)	91							

APPENDIX E

NORMALITY TESTS

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
BI1	,221	91	,000	,859	91	,000
BI2	,232	91	,000	,837	91	,000
BI3	,234	91	,000	,850	91	,000
BI4	,215	91	,000	,838	91	,000
BI5	,223	91	,000	,836	91	,000
PU1	,190	91	,000	,890	91	,000
PU2	,212	91	,000	,858	91	,000
PU3	,235	91	,000	,839	91	,000
PU4	,188	91	,000	,881	91	,000
PU5	,206	91	,000	,860	91	,000
PEU1	,210	91	,000	,868	91	,000
PEU2	,197	91	,000	,866	91	,000
PEU3	,208	91	,000	,846	91	,000
PEU4	,232	91	,000	,832	91	,000
PEU5	,199	91	,000	,853	91	,000
ICU1	,205	91	,000	,853	91	,000
ICU2	,213	91	,000	,849	91	,000
ICU4	,227	91	,000	,865	91	,000
ICU5	,236	91	,000	,851	91	,000
CM2	,211	91	,000	,863	91	,000
CM3	,212	91	,000	,886	91	,000
CM4	,243	91	,000	,843	91	,000
TM1	,209	91	,000	,886	91	,000
TM2	,243	91	,000	,864	91	,000
TM3	,197	91	,000	,897	91	,000
TM4	,179	91	,000	,910	91	,000

ROI1	,194	91	,000	,910	91	,000
ROI2	,184	91	,000	,913	91	,000
ROI3	,168	91	,000	,912	91	,000
PV1	,196	91	,000	,860	91	,000
PV2	,221	91	,000	,864	91	,000
PV3	,233	91	,000	,855	91	,000
PV4	,229	91	,000	,864	91	,000
AM1	,207	91	,000	,886	91	,000
AM3	,223	91	,000	,890	91	,000
AM4	,213	91	,000	,897	91	,000
a. Lilliefors Significance Correction						

APPENDIX F

COLLINEARITY STATISTICS (VIF)

	VIF		VIF
BI1	2,340	**CM2**	1,905
BI2	2,867	**CM3**	1,448
BI3	2,407	**CM4**	1,566
BI4	2,541	**TM1**	1,670
BI5	2,824	**TM2**	2,246
PU1	1,134	**TM3**	2,185
PU2	1,524	**TM4**	1,538
PU3	2,468	**ROI1**	1,963
PU4	2,256	**ROI2**	2,068
PU5	2,405	**ROI3**	1,761
PEU1	1,875	**PV1**	1,572
PEU2	1,766	**PV2**	2,130
PEU3	2,214	**PV3**	1,969
PEU4	1,792	**PV4**	1,507
PEU5	1,073	**AM1**	1,760
ICU1	2,592	**AM3**	2,071
ICU2	1,851	**AM4**	1,522
ICU4	1,597		
ICU5	2,527		

APPENDIX G

QUESTIONNAIRE (ENGLISH)

INDUSTRIAL ADOPTION OF MBSE MODEL QUESTIONNAIRE

Questionnaire Item	**Strongly Agree**	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**
"The organization that I work with is likely to integrate model-based approaches in the future."					
"Given the opportunity, I would like to utilize MBSE for handling systems design processes."					
"The use of model-based approaches would appear to be ideal for my line of work."					
"The overall consensus within my organization favors adopting MBSE in the near future."					
"I am open to a possible integration of model-based approaches to our workflow."					
"Using MBSE within system design phases would allow me to accomplish tasks more quickly."					
"Model-based approaches would improve the overall performance of the engineering team."					
"Model-based approaches would increase the overall effectiveness of our work."					
"I find MBSE to be a logical next step towards improved system design processes."					
"Model-based approaches would be useful to implement and utilize."					

"Processes regarding MBSE appears to be easy to comprehend."					
"Utilizing MBSE in my workflow appears to be relatively easy to do."					
"I am in no need for a training regarding how to use MBSE."					
"I am confident that I would master MBSE easily."					
"Overall, I would find MBSE easy to use."					
"Maintaining a system model artifact would play a vital role in conveying better communication across stakeholders of a project."					
"A system model would decrease the risk of miscommunication compared to document-based approaches."					
"Document-based approaches in systems design often fail to capture the current state of the project."					
"Model-based approaches may help in establishing a unified understanding of system behavior."					
"System models may pose as an effective medium for ensuring the availability of know-how within the organization."					
"Traditional systems design approaches fall short of managing complex system behavior."					
"Existing methods and tools may be rendered ineffective in dealing with modern systems design."					
"Maintaining a system model would increase the chance to adapt to potential design changes."					
"Model-based approaches may offer a more systematic development approach in dealing with organizational complexity."					
"The current toolsets and methodologies of MBSE are satisfactory for performing MBSE within the organization."					
"The existing toolsets and methodologies of MBSE are compatible with the ongoing structure of our workflow."					
"The modeling languages and tools are stable and easy to understand."					
"There appears to be a consistency among what is available in terms of toolsets and methodologies that enables performing MBSE."					
"The organization has the resources, knowledge, and the ability to invest in MBSE."					

"An investment towards adopting MBSE practices would yield increasing returns for the organization."					
"The time and budget expenses made towards adopting MBSE would benefit the organization in the long term."					
"The affiliated cost of adopting MBSE is justifiable for my organization."					
"Adopting MBSE would coincide with the current and long-term goals that the organization has."					
"Transitioning into model-based approaches would appear to be profitable for the organization."					
"There is a tendency to adopt a novel approach instead of maintaining legacy systems within the organization."					
"Transitioning from document-based processes would prove an arduous task for the organization."					
"Model-based approaches are mature enough to be utilized in organizational schemes."					
"I consider myself sufficiently knowledgeable in the topic of model-based systems engineering."					
"There are clear signs that the usage of model-based approaches has benefited other companies."					
"MBSE appears to be as a popular topic within systems engineering communities."					

APPENDIX H

QUESTIONNAIRE (TURKISH)

KATILIM FORMU VE MODEL TABANLI SİSTEM MÜHENDİSLİĞİ KABUL MODELİ ANKETİ

Amaç:

Bu çalışmanın amacı, Model Tabanlı Sistem Mühendisliği (MTSM) pratiklerinin sistem mühendisliği alanında çalışan kişiler tarafından kabul edilmesi ve kullanılmasını etkileyen faktörleri ortaya koymaktır. Faktörlerin araştırılmasından itibaren, MTSM'lerin pratisyenler tarafından benimsenmesini etkileyen en önemli faktörleri tahmin edebilecek bir model geliştirilmesi amaçlanmaktadır.

Araştırmaya katılmayı kabul ediyorsanız, lütfen aşağıdakileri doldurunuz. Bu anket iki bölümden oluşmnakta ve yaklaşık 20 dakika sürmesi beklenmektedir.

Bilinmesi Gerekenler:

Katılım tamamen isteğe bağlıdır ve istediğiniz zaman anketi doldurmayı bırakabilirsiniz. Kimliğinizle ilgili bilgi isteyen herhangi bir soru yoktur ve tüm cevaplar isimsiz olarak tutulacaktır.

Katılımınız için şimdiden teşekkür ederiz.

Araştırmacı: Alitan Bayramoğlu

E-posta: alitan.bayramoglu@metu.edu.tr

Telefon: +90 (541) 451 3727

Yukarıdaki bilgileri okudum ve bu araştırmaya gönüllü olarak katılmayı kabul ediyorum.

Kişisel Bilgiler

Aşağıdaki sorular kişisel bilgilerinizle ilgilidir. Lütfen size en uygun olan cevap için kutuyu işaretleyiniz.

Yaş: ☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 55 ve Üzeri
Eğitim Durumunuz: ☐ Üniversite ☐ Y. Lisans ☐ Doktora
İş Deneyiminiz: ☐ 1 Yıl ve Altı ☐ 1-2 Yıl ☐ 3-5 Yıl ☐ 5-10 Yıl ☐ 10 ve Üzeri

MTSM ile ilgili Tutum ve Görüşler

Aşağıdaki sorular MTSM kullanma konusundaki davranışsal **niyetinizi** anlamak için hazırlanmıştır. Cevaplar 1'den 5'e kadar şu şekilde ölçeklendirilmiştir:

5- Kesinlikle Katılıyorum, 4- Katılıyorum, 3- Kararsızım, 2- Katılmıyorum, 1- Kesinlikle Katılmıyorum

Lütfen size en uygun olan seçeneği işaretleyiniz.

SORU	Kesinlikle Katılıyorum	Katılıyorum	Kararsızım	Katılmıyorum	Kesinlikle Katılmıyorum
"Çalıştığım organizasyon, gelecekte model tabanlı yaklaşımları iş süreçlerine dahil etmeye yönelecektir."					
"Eğer imkan verilirse, sistem tasarım aşamalarında MTSM kullanmak konusunda istekliyim."					
"Model tabanlı yaklaşımların kullanımı, çalışmakta olduğum iş alanı için idealdir."					
Çalıştığım organizasyon içerisindeki genelgeçer görüş, MTSM'in yakın gelecekte kullanılmaya başlanması gerektiği yönündedir."					
"İş akışlarımıza model tabanlı yaklaşımların entegre edilmesine olumlu yaklaşmaktayım."					
"Sistem tasarım aşamalarında MTSM kullanmak iş paketlerini daha hızlı bitirmemi sağlar."					
"Model tabanlı yaklaşımlar çalışma ekibimizin genel performansını yükseltebilir."					
"Model tabanlı yaklaşımlar yaptığımız işlerin etkinliğini artırabilir."					
"MTSM'nin sistem tasarım aşamalarının geliştirilmesinde atılması gereken doğru bir adım olduğuna inanıyorum."					
"Model tabanlı yaklaşımların implementasyonu ve kullanımı, iş akışlarımıza uygundur."					
"MTSM ile ilgili süreçleri anlaşılır buluyorum."					
"İş akışımızda MTSM kullanmak bizim için kolay görünmektedir."					
"MTSM kullanımı ile ilgili bir eğitime ihtiyaç duymamaktayım."					

“MTSM’yi kolayca öğrenebileceğimden eminim.”					
“Genel olarak MTSM kullanımını basit ve anlaşılır buluyorum.”					
“Sistem modeli oluşturmak ve korumak, projenin paydaşları arasında daha işlevsel bir iletişim kurulmasında yardımcı olur.”					
“Sistem modeli, doküman bazlı yöntemlerle karşılaştırıldığında iletişimsizlik riskine daha az açıktır.”					
“Sistem tasarımında doküman bazlı yöntemler projenin güncel halini yansıtmakta yetersiz kalmaktadır.”					
"Model tabanlı yaklaşımlar sistem davranışının anlatılmasında daha kapsamlı bir anlayışı temin eder.”					
“Sistem modelleri, organizasyon içerisinde etkili bir bilgi dağarcığı oluşturulmasında etkili olabilir.”					
“Geleneksel sistem tasarım yöntemleri karmaşık sistem davranışlarını yönetmede yetersiz kalmaktadır.”					
“Modern sistem tasarımında halihazırda kullanılan yöntemler bekleneni karşılamamaktadır.”					
“MTSM ürün ağacını ve sistemlerin değişkenliğini desteklemektedir.”					
“Model bazlı yaklaşımlar organizasyonel karışıklıklara yönelik daha sistematik bir geliştirme ortamı sunmaktadır.”					
“Organizasyon içerisinde kullanılan araçlar ve metodlar MTSM kullanımı için uygundur.”					
“MTSM kapsamında kullanılan araçlar ve metodlar iş akışımız ile tezatlık içermemektedir.”					
“Modelleme dilleri ve araçlarının kullanımı ve anlaması kolaydır.”					
“MTSM kullanımında işlevselleştirilen araçlar tutarlıdır ve ihtiyaçların karşılanması için yeterlidir.”					
“Çalıştığım organizasyonun MTSM üzerine yatırım yapabilmesi için gerekli kaynağı, bilgisi ve yeteneği bulunmaktadır.”					

“MTSM pratiklerini entegre etmek, organizasyonum için uzun vadede yararlı olacaktır.”					
“MTSM pratiklerini entegre etmek organizasyonum için kazançlı olacaktır.”					
“MTSM pratiklerini entegre etmek için kullanılacak zaman ve bütçe giderleri organizasyonum için savunulabilir.”					
“MTSM pratiklerini kabul etmek organizasyonumun uzun vadedeki hedeflerine ters düşmemektedir.”					
“Model tabanlı yaklaşımlara geçmek organizasyonum tarafından kârlı görülmemektedir.”					
“Organizasyon içerisinde miras sistemlerin kullanımın devamına yönelik bir yatkınlık bulunmaktadır.”					
“Doküman tabanlı pratiklerden ayrılmak organizasyonum için zorlu bir süreç olacaktır.”					
“Model tabanlı yaklaşımlar organizasyonel yapılarda kullanılmak için yeterli olgunluğa erişmiştir.”					
“MTSM hakkında kendimi yeterince bilgili bulmaktayım.”					
“Model tabanlı yaklaşımların başka şirketlere sağladığı faydalar benim için aşikârdır.”					
“MTSM, sistem mühendisliği topluluklarında popüler bir konu gibi görünmektedir.”					

TEZ İZİN FORMU / THESIS PERMISSION FORM

ENSTİTÜ / INSTITUTE

Fen Bilimleri Enstitüsü / Graduate School of Natural and Applied Sciences ☐

Sosyal Bilimler Enstitüsü / Graduate School of Social Sciences ☐

Uygulamalı Matematik Enstitüsü / Graduate School of Applied Mathematics ☐

Enformatik Enstitüsü / Graduate School of Informatics ☐

Deniz Bilimleri Enstitüsü / Graduate School of Marine Sciences ☐

YAZARIN / AUTHOR

Soyadı / Surname : Bayramoğlu
Adı / Name : Alitan
Bölümü / Department : Bilişim Sistemleri

TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English) : INDUSTRIAL ADOPTION OF MODEL-BASED SYSTEMS ENGINEERING: AN INVESTIGATION WITHIN THE DEFENSE INDUSTRY

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master ☐ **Doktora** / PhD ☐

1. **Tezin tamamı dünya çapında erişime açılacaktır. /** Release the entire work immediately for access worldwide. ☐
2. **Tez iki yıl süreyle erişime kapalı olacaktır.** / Secure the entire work for patent and/or proprietary purposes for a period of **two year**. * ☐
3. **Tez altı ay süreyle erişime kapalı olacaktır.** / Secure the entire work for period of **six months**. * ☐

***** *Enstitü Yönetim Kurulu Kararının basılı kopyası tezle birlikte kütüphaneye teslim edilecektir. A copy of the Decision of the Institute Administrative Committee will be delivered to the library together with the printed thesis.*

Yazarın imzası / Signature .... **Tarih** / Date ....